Anatomy and Animation: Anatomically Based Animation Skeletons for Quadrupeds

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Anatomy and Animation: Anatomically Based Animation Skeletons for Quadrupeds

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Abstract

Constructing animation skeletons for quadrupeds is a complicated process, and knowing how to construct an animation skeleton for one type of quadruped does not guarantee the ability to effortlessly do so for another. This project explores how anatomy may ease the task of quadruped animation skeleton setup. Quadruped anatomy has been extensively studied and a method for animation skeleton setup based on anatomical information was explored using Autodesk Maya 2012. This method was based on the assumption that anatomical information could be incorporated into animation skeleton creation, thereby enabling the construction of an animation skeleton structure applicable to quadrupeds of different locomotion. It was discovered that this was hardly the case and the conclusion of this project has been that a better approach to animation skeletons is to construct them depending on the requirements of the project they are intended for rather than seeking to standardise how they should be set up.

Keywords: Quadruped, quadruped animation, quadruped anatomy, animation skeleton, 3D Animation, Autodesk Maya, locomotion, plantigrade, digitigrade, unguligrade.
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1 Introduction

Mankind has a long standing interest in depicting animals; it does not take more than to consider the cave paintings painted thousands of years ago to realise this [1]. As times move forward, animals are still very much present in our day to day life today and as such they are still being captured in drawings, photography and on film. Quadrupeds have been featured in animation for quite some time. The first full length cel animated movie, Snow White and The Seven Dwarfs from the late 1930s, included a number of quadrupeds, and quadrupeds have hardly been absent in animated movies since [2].

As new techniques for creating animations evolve, it seems obvious that man would desire to translate the animation of four legged creatures from traditional animation (animations drawn by hand using traditional, non-digital media) to three dimension (3D) animations. However, there is nothing that says that such a transition would be easy. Traditional animation has the advantage that, providing the artist has the necessary drawing skills; they are only limited by their own imagination. When working with pen and paper artists can shape their lines, and thereby their characters, pretty much however they want.

The method is not the same for 3D animation. Even though 3D animation is very much a creative process it is also a technical one, with huge sections of it being governed by technical principles just as much as it is by imagination. Surely, whatever an individual can imagine creating, be it a specific movement or something else entirely, they can also work towards achieving. However, it still stands that much of the 3D field is dependent on technical approaches and solutions.

Artist can no longer express the motion of a character by the stroke of a pencil, rather they have to first go through the process of not only creating the character as a 3D mesh, but also accurately construct an animation rig for it before they can even begin to animate it. In 3D animation, perhaps the most used approach to animating characters is by the use of an animation skeleton: A joint hierarchy corresponding to the anatomy of the character in question, the deformation of which is then used to drive the animation [3]. However, the construction of such a skeleton is a delicate
procedure, which sometime provides artists with not-so-easily overcome obstacles.

1.1 Research Purpose

There are many different approaches to animation skeleton setup; there are automatic and semi-automatic alternatives or artists can choose to set up their animation skeletons by hand. Arguably, in the case of realistic animation, setting up the skeleton by hand is the alternative chosen more often [3]. However, the construction of an animation skeleton is not an easy feat, and then comes the continued rigging of it. This process requires a reasonably skilled user who at least possesses a basic understanding of anatomy, as well as the knowledge of the software they are working within [3].

There are obvious differences between bipeds and quadrupeds. Apart from the obvious differences that meet the eye a main difference between them is that most people have a fairly good understanding of how a biped moves, due to being bipedal themselves. Likewise, most artists tasked with setting up an animation skeleton for a human character probably have a rather good understanding of the human anatomy and skeletal structure, and then there is always the possibility of using oneself as a go-to reference.

Human skeletal structures do not vary much, at least not in a manner that will largely influence how the animation skeleton should be constructed. Quadrupeds, on the other hand, cover a comparatively much larger spectrum of variations and having successfully created a rig for one type of quadruped does not guarantee the ability to effortlessly do so for another.

The questions then are: What are the exact differences between quadrupeds and bipeds? And how should these differences be treated in respect to animation skeleton setup and rigging? One might think that after centuries of depicting, and not to mention living in close contact with, animals would have given man enough knowledge of quadruped anatomy to allow pretty much anyone to understand quadrupeds; including the differences between different types of quadrupeds. This does not seem to be the case; there may be many examples of when man has managed to accurately capture quadruped anatomy and motion [4]; however, there are also a number of cases when man has failed to do so [1]. We may have a basic *instinctual* knowledge of quadrupeds; knowing how they are supposed to look and move and
readily being able to tell when something is not looking or, in the case of animation, moving correctly but at the same time being incapable of pinpointing exactly what it is that is wrong.

Following on the belief that the key to better understanding animation skeleton setup for quadrupeds lies in understanding real life quadruped anatomy, and in knowing how the skeletons of different types of quadrupeds are constructed compared to one another, this research is carried out in order to seek a practical and feasible method to use anatomical information in order to develop a generic quadruped animation skeleton setup which will work for different kinds of quadrupeds regardless of what type of locomotion they adopt.

The purpose of this project is to research the possibility of simplifying animation skeleton creation for quadrupeds; to discover if basing animation skeletons on anatomical information will allow the user to construct these skeletons using a standardisation of joints. If this is possible it will hopefully not only save time by simplify the animation skeleton creation process but also, by extension, make quadruped animation more accessible to novice 3D users.

1.2 Research Aims

Following the complications presented in the previous section, the aims of this research is to explore the field of quadrupeds in regard to animation with the purpose to untangle some of the problems of quadruped animation skeleton setup. The history of animation will be reviewed with a focus on quadrupeds. This will be researched in order to discover how quadruped animation has been treated in the past, as well as to outline what different approaches there is to realistically capture the movements of real life creatures on film.

Furthermore, there is a need to research what different approaches there are to creating quadruped animation skeletons, either by hand approaches or automatic and semi-automatic methods. This is necessary in order to discover if, and how, quadruped anatomy is used for constructing quadruped animation skeletons.

Lastly, different anatomical structures of real life quadrupeds will be studied in order to explore the possibilities of developing a quadruped animation skeleton
structure which is anatomically based and which can be used for a range of different types of quadrupeds regardless of what kind of locomotion they adopt. Once such a skeleton has been created it will have to be tested in order to find out how functional it is. It will also have to be taken into consideration how well the animation skeleton lends itself to further rigging.

1.3 Research Questions

The purpose of this project is to research the possibility for constructing animation skeletons for quadrupeds based on real life quadruped anatomy. On which follows the complication that quadruped skeletal anatomy is rather varied. Thus, it might prove to be a challenge to combined different anatomical structures into one skeleton which is then to function for all types of quadruped locomotion. Specific questions which will be considered in this research are as follows:

- What are the anatomical differences between quadrupeds in regard to their skeletal structures?

- How should these differences be treated in regards to animation and the setting up of animation skeletons for quadrupeds?

- Is it at all possible to create a generic quadruped skeleton which maintains its functions regardless of what kind of quadruped animal it is used for?

1.4 Limitations

There have been some limitations placed upon the work presented in this report. The foremost of these limitations are as follows:

Although quadruped anatomy will be thoroughly researched, the focus will be in large part on the anatomical structures of the animals’ limbs. This is because the limbs of quadrupeds are what provides the most apparent skeletal variety, as well as how the limbs are a clearly important part of animation skeletons. If the limbs of an animations skeleton are not successfully constructed and rigged, it is obvious that there will be problems when the time comes to animate the character in question.
The experimentation part of this project will be carried out using Autodesk Maya 2012. The research is heavily focused on skeletal anatomy and muscles will not be taken into consideration. Likewise, the different muscular functions available within the 3D software will not be explored. Also, the constructed skeletons will be evaluated based on how adaptable they are, as well as on how suitable they are for continued rigging. However, due to time constraints, it is unlikely that any of the skeletons will be fully rigged or extensively animated.

It is important to note how the research presented in this paper is not aimed at experienced 3D artists. Rather, the focus is to find a method to base animation skeletons on anatomical information in order to make the process of animation skeleton setup more comprehensible for individuals who are just starting out working with quadrupeds in 3D.

This research is focused extensively on quadrupedal mammals. However, bipeds may be included to some extent, but then primary for the purpose of comparing and contrasting. Moreover, amphibians and primates will not been taken into consideration in this project.

Lastly, the technical solutions and mathematics behind the various automatic and semi-automatic methods for animation skeleton creation presented in the Technical Background section below are not going to be covered in this report.

### 1.4.1 Definitions

The word ‘animal’ is used frequently in this report and could be taken to include a wide range of creatures. For the length of this report, it will primarily and unless otherwise stated refer to quadrupedal mammals.

The term ‘animation skeleton’ is used frequently during the length of this report; it has not been replaced with the simpler ‘skeleton’ due to the large amount of anatomical references which are contained in the report as well. For clarification, ‘animation skeleton’ will be used while referring to the joint hierarchies utilized to animate characters in 3D, whereas simply ‘skeleton’ will be used when referring to the real life bone and joint structures found in actual mammals. There is however
exceptions to this and in these case the context should be enough to make it clear which kind of skeleton is being discussed.

There are also frequent references to ‘different types of quadrupeds’ and ‘quadruped locomotion’ being made in the report. These terms are presented in greater detail in section 3.2.5, wherein the terms plantigrade, digitigrade and unguligrade are also explained.

During the length of this report the bones of real life skeletons are referred to in scientific terms, and the bones of animation skeletons are named accordingly. It has been noted that this may be confusing for readers who are unfamiliar with such terms and, if this be the case, it is suggested to consult sections 3.2.3 and 3.2.4 as well as Figures 5 and 6 on page 18 for clarification.

1.5 Expected Results

As stated above, the aim of this research is partly to gain a better understanding of quadruped anatomy and partly to develop a quadruped animation skeleton structure which is functional regardless of the kind of locomotion the quadruped in question adopts. The main idea is that not only would an anatomically sound animation skeleton be easier to understand for an inexperienced user but it would also, as most mammals share a basic skeletal structure [1] [5], provide an element of recollection regardless of what type of animal the animator is creating the skeleton for.

2 Method

Before embarking on any project it is first necessary to choose a method to be used in order to acquire the information needed. Because there are two parts to this project; the first focused on the study of quadrupeds and their anatomy; and the second being to use the anatomical information gained to construct animation skeletons using 3D software, there is also a need for two different methods.
2.1 Choice of Method

There is a dual approach to this research. Many of the questions outlined in the previous section required a study of previously published literature in order to be answered. Thus, a literature review will be carried out. Other questions will require a certain amount of experimentation in order to be answered.

2.2 Description of Method

The theoretical information that will be researched as part of this project can be divided into two main areas: The first will cover 3D and animation with a focus on quadrupeds and the second will be about researching the anatomical structures of real life quadrupeds. The focus is going to be on the skeletons and skeletal differences of quadrupeds in general and the different skeletal structures of quadrupeds’ limbs in particular.

The experimentation part of the project will be carried out using Autodesk Maya 2012, hereafter most commonly referred to as simply Maya, and will in large be focused on how to best construction the limbs of animation skeletons for quadrupeds. It will also be considered how readily the same basic animation skeleton structure can be adapted to different types of quadrupeds, and the question remains whether or not it is practical to do so.

3 Theoretical Background

Because animals are so familiar to humans, one might be encouraged to think that we would have a somewhat unfailing knowledge of animal movement by now, however this is not always the case [1]. Man certainly has an intuitive understanding of animals and animal motion, at least when it comes to animals we are able to frequently observe. This is not to say that everyone knows exactly how animals function; what their anatomy is like and what the anatomical differences between them are exactly.

It is obvious that there are differences between a racoon, a dog and a horse. Everyone can see this and most will probably be able to deduce that, apart from the obvious differences in outer appearance, there are also differences in locomotion. These
locomotion differences are tied to skeletal variations between mammals. Some people may even be able to recall specific terms, such as plantigrade, digitigrade and unguligrade. These are terms of vital importance when it comes to understanding quadruped movement, for they represent some of the most basic differences between quadrupeds. They are also vitally important for understanding how to construct animation skeletons for quadrupeds. The topic of quadruped locomotion will be discussed later in this report. First however, there will be a closer look into animation and different techniques used for realistically capturing and transferring the motions of quadrupeds from real life to the screen.

3.1 Animation

A basis for good animation is undoubtedly the understanding of the natural movement of the creature the animator intends to animate. However, knowing the name of every bone and every muscle of a particular animal may not be of paramount importance. Having an understanding for how those bones and muscles function, and knowing their general elasticity and flexibility, is arguably far more vital when it comes to correctly capturing animal motion [1].

3.1.1 Understanding Animal Motion - Early Work

In the mid-1800s, just before the introduction of motion pictures, the photography work of Eadweard Muybridge greatly contributed to the understanding of animal motion [6] [1]. Muybridge developed a technique to rapidly take several pictures of animals in motion, thereby ensuring the capture of animal gaits in more detail than anyone had been able to do before this time [1]. The results of Muybridge work, as well as extensive information regarding the different gaits animals adopt, can be found in the book Animals in Motion [4].

Robert McNeill Alexander’s work further adds to the knowledge of gaits. Alexander’s work within the field is extensive and he has published a number of reports relating to animal locomotion [6]. Amongst other accomplishments Alexander developed the Dynamic Similarity Hypothesis, a theory relating to when animals will change from one gait to another [7] [6]. Although this may not seem to be of great importance in regards to animation, where the gait of a single animal character might be more of an artistic choice than a scientific one, it could prove useful in case an
animator has to animate several different kinds of animals in the same 3D scene.

3.1.2 Animation Techniques

There are a number of techniques to be used for creating realistic character movement based on real life footage. Rotoscopying is one of the oldest of them, having been used since the beginning of the 18th century, and is still in use today [6]. Rotoscopying basically involves animators tracing the desired movement from a video capture of the creature (or object) in question frame by frame in order to accurately capture motion [6]. Rotoscopying has the advantage that it enables the creation of highly realistic and well flowing character motions, which is something that can be quite difficult to achieve otherwise [6]. On the other hand, rotoscoping has a main drawback in that it is time consuming, as the animator must work frame by frame. It is also limiting in the sense that it can only be used to recreate already captured motions. This means that only animal motions that are physically and practically doable in real life will make it to the screen using this technique.

Motion capture is a more recent technique used for transferring real life motion to the screen. It is also perhaps more associated with 3D animation than rotoscoping. In recent years, motion capture has progressed from being something of an enigma in the field of animation (some even taking it so far as to refer to it as “Satan’s Rotoscope” [8]) to being an increasingly popular approach to animation. It has been almost exclusively available to high end productions made by large companies up to recently, however it is now becoming more and more accessible to smaller studios as well [8].

Motion capture typically involves the capture of the motion of an actor, using tracking and some kind of markers. The movement is translated to a 3D model and then further worked on by an animator. Motion capture has the advantages that it provides a quick method for capturing motion data; readily creating detailed motions which would take considerably longer to achieve if it was to be created by hand by an animator [8]. It is also profitable to use for situations including large amount of people; such as larger crowds or background animations which do not require as much detail as a close up shot of a person or a couple of main characters would [8].

A current drawback to motion capture is that it cannot always fully capture the finer motions of the actors; such as subtle hand and finger movements and more
delicate facial expressions. It is also not fool proof and the amount of work that has to be carried out in order to finalise the animation after the initial motions are captured may vary greatly [8]. Furthermore, motion capture has the disadvantage that it is currently limited to “what animals or creatures can be convincingly captured” [8].

Because the use of markers is still such a big part of motion capture using animals as subjects for providing motion becomes complicated. Just because it may be possible to put tracking equipment on a dog or a horse does not make it practical to do so. Then, there is the question of whether or not it would be at all possible to acquire any useful motion data out of such a session. It is also not optimal to have an actor perform as an animal [8] and in this case it is reasonable to believe that the animator will attain far better results by animating the creature or character in question directly by hand.

There is currently work being carried out in order to develop motion capture techniques that does not require any special equipment to be worn by the subject in order for the tracking of the subject’s motions to take place [8]. Although this possibly could open up motion capture to be more readily used with animals, it still stands to reason that animals, though trainable, probably never will be able to perform in the same manner human actors do. Thus using motion capture to animate animal characters continues to appear futile.

Because of the complications using motion capture for animal character motion would bring, as well as the limitations placed on what motions could be captured with a technique such as rotoscoping, perhaps the best approach to animating animal characters is to study the natural movement of animals and incorporate this knowledge of movement into animations made by hand [6].

### 3.1.3 3D Animation and Animation Skeletons

In 3D animation, characters are often represented as a polygonal mesh, a collection of three dimensional vertice points connected through straight edges to form an object in 3D space [9]. It would be both extremely difficult and extremely time consuming, not to mention more or less impossible, to animate such a mesh by directly deforming it vertex by vertex [10]. Therefore, it is a common practise to use what is known as an animation skeleton, which may also be referred to as an Inverse Kinematics (IK) skeleton or just a skeleton [3], to assist in this task. In its simplest form, an animation
skeleton is a series of joints and in 3D animation “most deformations of a character will be based on joints” [11, p. 90].

For a more complex character, such as a quadruped, the animation skeleton will consist of several joint chains. A joint chain is exactly what it sounds like: A number of joints and bones connected in a series [11]. These chains are then connected to each other and the mesh, or the ‘skin,’ of the character is bound to the joints. Once bound, these joint chains will be able to control the mesh and deformations of the characters may be accomplished by the animator moving the joint chains of the animation skeleton accordingly.

Animation skeletons are widely used and highly practical, even offering animators the possibility to roughly block out the animation of a character without having to see the character mesh by using the skeleton as a visual guide instead [11]. However, animation skeletons are not perfect and far from being without liabilities. Animation skeleton setup is the first part of the rigging process, and rigging have been described as being “by far, the most confusing and typically misunderstood procedure in the 3D pipeline process” [11, p. 86]. The creation of animation skeletons is not always a straightforward process and in the case of quadrupeds, it is a poorly documented one at that. The placement and orientation of the joints making up the skeleton must be carefully considered or else the animator might end up with a bound character which is just plain difficult to animate [12]. Animation skeleton setup for realistic or semi-realistic characters does require a skilled user who at least possesses a basic understanding of anatomy [3]. And even if an experienced user may construct the initial skeleton rather quickly, the rigging of it might prove to be a time-consuming process needing a large amount of testing and adjusting in order for good results to be obtained [3].

Because animation skeletons are such an important part of animation, and because constructing them by hand is such a delicate procedure, it follows that there has been a significant amount of effort put into easing this task. There exist a number of automatic and semi-automatic approaches to animation skeleton creation, a few of which are briefly outlined below.

Autodesk Maya 2012 comes with a function to automatically create an animation skeleton for biped characters. It is called the Human IK Skeleton Generator, and it also
provides the possibility to automatically rig the created skeleton for animation with Inverse Kinematics [9]. Autodesk 3D Studio Max provides a system that not only enables the user to quickly create a character rig but also offers a range of parameters to modify it in order to make it suitable for a wider range of characters, biped and quadruped alike [13].

As mentioned previously, within the field of 3D, the topic of quadrupeds is not all that well documented, especially not in any manner that is easily accessible and easily understood by individuals just starting out in the field. However, a number of interesting research papers regarding quadruped animation skeletons have been published in recent years. The most interesting ones in regard to this project are those that cover quadruped anatomy and the modification of animation skeletons to fit a larger spectrum of quadruped characters.

In 2003, Pin-Chou Liu, Fu-Che Wu, Wan-Chun Ma, Rung-Huei Liang and Ming Ouhyoung constructed a method for automatically rigging a 3D model [10]. Although their project seems to have been reasonably successful, the skeletons generated are not anatomically based and does arguably have features which make them unsuitable for realistic animation; such as an unfortunate placed spinal column [3] [10]. Furthermore, judging by the visual data published in the report, it would also seem the resulting skeletons were somewhat disordered. They appeared to include joints which did not logically correspond to any joints found in real life quadruped skeletons and did not seem to fill any specific function in regards to animation either.

In 2007, Grégoire Aujay, Franck Hétroy, Francis Lazarus and Christine Depraz developed a method to automatically set up a so called harmonic character skeleton suitable for realistic 3D animation [3]. Aujay et al suggest that when it comes to realistic animation, the skeleton to drive the animation is most often set up by hand, and continue to list a couple of drawbacks associated with this approach: They argue that it is time consuming and requires a reasonable skilled user, and that it also requires a great deal of testing before the desired result can be achieved [3]. They also argue that the automatic and semi-automatic methods available for skeleton setup at the time often comes with problems such as little control over the result and undesired joints [3]. Furthermore, they say that "[automatic and semi-automatic methods for rigging] rely on the topology and the geometry of the model only, which is not sufficient for realistic animation where the anatomy of the model does not completely
match its geometry” [3]. Their method, in addition to using the topology and geometry information derived from the model, also takes anatomy into account when setting up the skeleton. The resulting animation skeletons are reported as being very close to the ones set up by an experienced animator and they also correspond well to real life quadruped skeletons [3].

Also in 2007, Ilya Baran and Jovan Popović created a prototype program called Pinocchio which would make animation easier for non-experienced users [14]. This program involves the use of a generic skeleton that is adapted to fit the character that is to be animated. In the project report, Pinocchio seems to have been most extensively tested with biped characters; however it is reported to work for quadrupeds as well.

Lionel Reveret has been involved in a number of research concerning quadrupeds in 3D. In 2005, Reveret, together with Laurent Favreau, Christine Depaz and Marie-Paule Cani, developed a method to generate animation skeletons which could be adapted to a wide range of quadrupeds, allowing for the creation of animation skeletons for creatures that were not originally included in the skeleton database at hand [6] [15]. The adaption of these skeletons was controlled by three different parameters, which are below [15]:

- The height of the animal in question.
- The bending of the vertebral column.
- A hoofed (unguligrade) versus plantigrade parameter.

This suggests that it is highly possible to use adaptable quadruped animation skeletons with good results.

### 3.1.4 Animation Skeleton Problems and Examples

As is evident by the section above, there exist a couple of different approaches to animation skeleton setup to choose from. However, the choices an artist has to make in regards to animation skeleton setup and rigging rarely ends with just picking a method. Even though it may be somewhat overreaching, it is not entirely unfound to say that there may be as many methods for rigging as there are artists trying their hand at it. Even if limited to setting up the animation skeleton by hand, there will still be a number of approaches to the process. Again, different animators will have different preferences and different projects will have different requirements. For example, a
character with shoes on, or as may be a more believable scenario in the case of quadrupeds; a character without very detailed paws, will probably not require a set of anatomically correct joint chains representing their phalanges. In this case, a simplified skeletal structure is preferable.

Likewise, there is really never a need for all the vertebrae found in real life skeletons to be represented as individual joints in an animation skeleton. This in turn purposes the question of how many joints there should be in the spine of the character. Although there might be suggestions and recommendations, there is no certain answer; again it depends on the character in question and the opinion of the person creating the skeleton. Then, there are the cases when instead of simplifying by decreasing the number of joints in relation to real life skeletons, animators will instead add joints. These joints typically make little sense anatomically but are useful for animation purposes [3]. Examples of such joints are so called roll-bones, double-knee joints and joints which for different reasons may be added to the head of the character. Below are a few examples of different animation skeleton structures:

![Figure 1. Simple quadruped character.](image)
Figure 1 and 2 above both illustrates an example of a very simple animation skeleton for a quadruped character. Although the character in question is not a real life creature, its anatomy is still inspired by a real life quadruped (a dog). The animation skeleton, though, is based on the topology of the model rather than on anatomical information. Joints are primarily located at main articulations and the limb joint chains consist of a minimum of joints. There is one joint added to the head of the character that make little sense anatomically, this joint is used for the eye of the character.
Figure 3. Maya’s Human IK skeleton with roll-bones included for Lower Arms and Legs.

Figure 4. Maya Human IK default skeleton without roll-bones.
Figures 3 and 4 depict two examples of animation skeletons created by using the Maya Human IK Skeleton Generator. The skeleton in Figure 3 includes roll-bones for the Lower-Arms and Lower-Legs and Figure 4 displays the default skeleton without roll-bones. The Maya Human IK Skeleton Generator also supports adding roll-bones for the Upper-Arms and Upper-Legs. Roll-bones probably make more anatomical sense when used in the lower limbs, since these are parts of the human skeleton that actually consists of two bones: The radius and ulna for the arms and the tibia and fibula for the leg. In the human skeleton, these bones are of approximately the same length, but different in thickness, and are parallel to each other. Roll-bones thus are hardly anatomically accurate, as there is no joint found in the middle of neither the lower arm nor the lower leg in real life. However, they do offer the addition of anatomical correct features for human animation skeletons. The perhaps most common use for roll-bones is to enable a character’s “forearm to twist when the wrist rotates” [16, p. 261] which in large is what happens in real human arms as well [16].

3.2 Anatomy

As previously stated the aim of this project is to research the advantages and disadvantages of anatomically based animation skeletons. The supposition is that a recognition factor between animation skeletons constructed for different kinds of quadrupeds would be of help when it comes to learning the process of constructing and rigging animation skeletons. The question is whether this is practical or not? The setting up of an anatomically correct animation skeleton is certainly possible. Whether or not the resulting skeletons will prove to be easy to understand and work with is a different matter entirely. An animation skeleton, no matter how anatomically correct it may be, will be of little use if it proves to be unsuitable for further rigging. Anatomically based animation skeletons will be covered later in the report. For now, focus will be on finding the anatomical differences that discern different types of quadrupeds from one another.

3.2.1 Basic Skeletal Anatomy

In order to better understand the basic skeletal structure of quadruped mammals, it is helpful to consider how the human skeleton would appear if the human were placed on all fours; this can be seen in Figure 5. Placing the human skeleton in a ‘crawl’ position makes it easier to see the correlations between the human skeletal structure and a
quadruped one:

The skeletal structures are largely similar, although the bones and joints obviously vary in shape and sizes. There is the skull, the cervical, thoracic and lumbar vertebrae,
the ribcage, the sacrum and the pelvic girdle, and a number of bones and joint making up the limbs. Some general skeletal differences between man and animal are outlined below [5]:

- The spinal column, which is vertical for man and horizontal for animals.
- The neck, which is shorter for man and longer for animals.
- The humerus and femur, which are long and extending outwards from the trunk for man and short and close to the trunk for animals.
- Animals have a reduced number of digits and following this the joints of the limbs are located in different positions.

If a human skeleton is placed on all four and compared to the skeletal structure of an animal, it is easy to observe that the locations of the mandibular\(^1\) joints, the shoulder joints, and the hip joints are rather similar, whereas the placement of the elbow joints, carpal and tarsal joints, knee joints and phalangeal joints are more differentiated. Likewise, if the skeletal structures of different types of quadrupeds are compared, the mandibular, shoulder, elbow, hip and knee joints and, to some extent, the carpals and tarsal joints would be in similar positions. The largest variations between quadrupeds occur in the limbs. The variations that are of most interest in regards to this project are relating to the carpals, tarsals, metacarpals, metatarsals and phalanges. Hence, the focus of the next section will be on the anatomy of the legs and paws of different kinds of quadrupeds.

### 3.2.2 The Limbs

Arguably, the largest skeletal variations between quadrupeds occur in the skeletal structure of the limbs. In most mammals the leg bones lie in a sagittal plane (in contrast to amphibian who’s leg bones lie in more of a transversal plane) [3]. The limbs of quadrupeds, similar to most creatures, are made up by a number of bones and joints. This is in a large part why it can be so complicated to know how to place the joints in the limb joint chains when constructing animation skeletons for quadrupeds. While these bones are largely the same as the ones found in human limbs, they do differ in shape, size and sometime also number. These differences make the joints of the limbs be located in different positions [5]. Below is an outline of the bones of the limbs of a human, as well as an explanation of how these bones are laid out in quadrupeds.

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\(^1\) The mandibular joints connect the mandible (jaw bone) to the skull.
3.2.3 The Thoracic Limb

The bones of the upper limb of a human are as follows [17]:

- The humerus, which connects to the trunk.
- The radius and ulna, which together make up the forearm.
- The carpals, which are placed in two rows and make up the wrist.
- The metacarpals, which make up the palm of the hand.
- The proximal, intermediate and distal phalanges, which makes up the fingers.
  There is no intermediate phalange in the thumb.

3.2.4 The Pelvic Limb

The bones of the lower limb of a human are as follows [17]:

- The femur, which connects to the pelvic.
- The tibia and fibula, which together make up the lower part of the leg.
- The tarsals, which are placed in rows and make up the heel.
- The metatarsals, which make up the main part of the foot.
- The proximal, intermediate and distal phalanges, which makes up the toes.
  There is no intermediate phalange in the big toe.
- The patella, or kneecap.

Quadruped skeletons have much the same bones, however they obviously do differ from the bones found in humans. It is for example not uncommon for the radius and ulna and the tibia and fibula of quadrupeds to be fused together to different extents. This is very evident in horse skeletons [5]. Moreover, the number as well as the placement of the carpals and tarsals, metacarpals and metatarsals, and the phalanges varies greatly between quadrupeds [5].

3.2.5 Plantigrade, Digitigrade or Unguligrade?

Quadrupeds can be categorised depending on what kind of locomotion they adopt. When it comes to understanding animation skeleton setup for quadrupeds, locomotion is vitally important. What locomotion a quadruped adopts will govern the distinction between the animal’s leg and its paw. There are three main kinds of locomotion:
Plantigrade locomotion means that the creature in question walks on the sole of their foot or paw. Humans are plantigrade [17]. Bears and raccoons are examples of quadrupedal plantigrades. Interestingly enough, plantigrade animals are probably the ones most likely to be successfully bipedal on occasion.

Digitigrade animals, as suggested by the name, support themselves on their digits. Canines and felines are digitigrades [5].

Lastly, there is unguligrade locomotion. Unguligrade animals may also be referred to as hoofed animals and they walk upon their distal phalanges. Horses belong to this category [5].

![Figure 7. Comparison between different types of locomotion.](image)

In summary, depending on if a creature is plantigrade, digitigrade or unguligrade the number of bones that can be said to be included in the leg of the animal will differ. This should be taken into consideration when setting up animation skeletons since it will affect how the joints of the limbs should be set up in order for the skeleton to bend in an appropriate manner.

4 Realisation and Results

With all these different options for animation skeleton setup, combined with the differences in anatomy between real life quadrupeds, it is not surprising that people
might get confused over how best to construct animation skeletons for quadrupeds. The method tested in this paper is a purely anatomically based one: The joints of the animation skeleton will be placed based on how they are located in real life skeletons rather than based on geometric information from a 3D model. It is hardly a new idea to use anatomical references to help in the process of rigging; however usually when basing animation skeletons on anatomical information some simplification typically occurs which diminishes the accuracy of the placement, as well as the number, of joints. The tarsals and carpals are an example of this and will be discussed in greater detail later in the report.

The main advantage of this approach is that there should always be a set number of joints to include in the limb joint chains of the animation skeleton and thus the animator will not have to consider how many joints to use. One advantage of this is that the resulting skeleton should be adaptable to all kinds of quadrupeds since it will include all the necessary bones and joints. A drawback then is that with more joints comes more work, and also it is not unlikely that some joints may be abundant in certain skeletons. Unnecessary joints are something that should be avoided in animation skeleton and the question is whether the recognition factor gained by having them in the skeleton will balance out what extra time and work they may bring.

### 4.1 Constructing the Animation Skeletons

The basic idea of the anatomically based animation skeletons is that it should be as close to its real life counterpart as possible while remaining practical, as well as being adaptable and allow for use with plantigrade, digitigrade and unguligrade characters without the animator having to add or remove joints. These two features go hand in hand; since many animals “parallel each other anatomically in many respects” [1]. The anatomically based animation skeleton would be constructed to include the necessary joints for all types of quadrupeds. However, as always when constructing animation skeletons based on real life skeletons, some simplifications must be made.

It has already been stated that the vertebrae column is an area that requires simplification when constructing animation skeletons. This can be related to a statement included earlier in the report regarding how knowing the functionality and bendability of the spinal column of a particular creature is more important than
knowing the specifics of every individual vertebra. Then there is the matter of the
limbs. Here too, some simplifications are needed. Because this research is not
concerned with highly detailed paws, there is no need for including a full set of
phalanges. The same goes for the carpals, metacarpals, tarsal and metatarsals.

In real life skeletons, there are a number of carpals and tarsals and they are
positioned in two rows. In animation skeletons the wrist, which is the transition from
the radius and ulna via the carpals to the metacarpals for the thoracic limb (tibia and
fibula via the tarsals to the metatarsals for the pelvic limb) is often represented by just
one joint. While the carpal/tarsal region can be viewed as just one articulation, the fact
that it is comprised of several small bones placed close together does provide it with
some special features. For example, this articulation is not a ‘sharp’ bend, such as one
would observe in a human finger or elbow. Rather it has an appearance more flat,
somewhat but not entirely, similar to that of a knee.

For animation skeletons some artists like using a double joint for the knee of their
character. Supposedly, this can help to better depict the appearance of the bending
knee that is the result of the patella [18]. While this may be profitable in the case of
humans and other plantigrade characters, it seems somewhat unnecessary for other
kinds of quadrupeds. The skeletal structures of digitigrade and unguligrade creatures
typically places the knee considerably higher up the leg than it is found in humans and
plantigrade quadrupeds [5]. Due to this, the knee is not as pronounced, and a double
knee animation skeleton setup seems redundant. However, including more joints for
the carpals and tarsals for quadrupeds might aid in creating a similar effect for an
articulation that is more pronounced and thus add some nice anatomically based
functionality to the animation skeleton.

4.1.1 The First Anatomically Based Animation Skeleton

A number of animation skeletons were set up for this project. All of them derive from
a first skeleton. This first skeleton is a digitigrade skeleton created to suit a larger type
of dog. It was created with anatomical references from previously studied literature [5]
[1] and also made to suit the dog model which can be seen in Figure 8 below:
Figure 8. Quadruped character mesh.

Figure 9 displays the reference drawings used both for the modeling of the dog and the positioning of the joints in the animation skeleton. The skeleton was created using the Maya Joint Tool with default settings and reoriented with the Orient Joint function (also default settings) upon completion. Figure 10 below displays the resulting animation skeleton:
Two carpal/tarsal joints were added and the phalanges were placed in accordance with a real life dog skeleton. Already at this stage, it is becoming apparent that the carpals/tarsal regions may prove a problem and that the extra joints included at this articulation might do more harm than good. Also note that no claw bone was included and that the skeleton thus is short of one phalanx for every limb.

4.1.2 Adapting the Skeleton

Adaptability was a main prospective advantage of the anatomically based skeleton. It was to be tested how well this first digitigrade skeleton could be adapted to suit unguligrade and plantigrade quadrupeds. When adapting the animation skeleton to suit an unguligrade quadruped, the skeletal anatomy of a horse was used for reference [5]. The animation skeleton was altered by changing the local length and rotations of the bones and joints respectively. Figure 11 displays the adapted skeleton.
While adapting the digitigrade skeleton to suit an unguligrade character a couple of problems became apparent. These problems are described in the next section.

4.1.3 Animation Skeleton Problems

The lower part of the limb, from the carpals and tarsals and downwards, was suspected to be possibly problematic from the beginning, and this suspicion turned out to be correct. In the animation skeletons, it is clear from just visual information that the carpal and tarsal area is problematic. There are too many joints crammed into too small a region. In the case of the unguligrade skeleton, they almost end up on top of each other. Furthermore, the larger number of joints is not improving the skeleton. When the digitigrade skeleton was tested with an IK setup, the additional carpal and tarsal joints were a nuisance and the attempt to use a reverse foot function yielded poor results. It seemed reasonable to remove one of these joints in favour for better results and a simpler skeleton.

Likewise, the number of phalange joints turned out to be a slight problem as well. Because the distal phalange, or claw bone, was not included in the digitigrade skeleton the unguligrade skeleton is without an important bone. While it is possible to construct a functional unguligrade animation skeleton without this missing phalanx, adding it to the digitigrade skeleton would not bring any significant improvement. This is why an additional phalange has not been added, even though the absence of it makes the
Lastly, when adapting the digitigrade skeleton to an unguligrade, it became evident that there was a need for additional neck joints in order for the animation skeleton to be suitable for the unguligrade quadruped.

Due to these problems, it was decided not to further adapt the skeleton and it was not tested how it would suit a plantigrade quadruped. Instead, the first skeleton was altered in order to eliminate some of these problems and then further experimentation was completed with the resulting skeleton. The resulting skeleton was later also altered for unguligrade, as well as plantigrade, locomotion. Figure 13 demonstrates the altered digitigrade skeleton:

![Figure 13: The altered digitigrade skeleton with the corresponding character mesh.](image)
As can be seen in Figures 12 to 14 above, one of the two carpals and tarsals have been removed for each limb and the phalanges have been repositioned. However, no new joints have been added yet. This animation skeleton is not yet considered complete and will require more experimentation in order to be finalised.
4.1.4 Adapting the Skeleton to Suit Different Locomotion

A main aim of this project has been to research the possibilities of constructing a quadruped animation skeleton structure that can be used with different types of quadruped locomotion. This does not necessarily mean the adaptation of one skeleton to suit another kind of locomotion, even if this it the way it has been done here. Rather the idea was to be able to pinpoint how many joints should be included in a skeleton for it to be functional with all three types of locomotion. Figure 15 below illustrates a solution with 7 joints used for each limb; Humerus, Radius/Ulna, Carpal, Metacarpal, Proximal Phalanx, Intermediate Phalanx and Distal Phalanx/Phalanx End joints for the thoracic limb and; Femur, Tibia/Fibula, Tarsal, Metatarsal, Proximal Phalanx, Intermediate Phalanx and Distal Phalanx/Phalanx End joints for the pelvic limb. However, this setup proved to be best suited for the digitigrade skeleton, plausible for the unguligrade skeleton, and unsuitable for the plantigrade skeleton. These skeletons can be viewed below in Figures 15, 16 and 17 respectively:

![Digitigrade animation skeleton.](image)

Note that an additional neck joint has been added to the structure in order to improve the unguligrade skeleton.
Apart from the differences occurring in the limbs, it has been found that the main anatomical differences between the studied digitigrades and unguligrades that affect animation skeleton construction is found in the neck and tail. The vertebrae in the unguligrade neck tend to dip downwards slightly before rising up to the skull. This seems to be an effect of the curvature of the spinal column as well as the length of the spinous processes. The spinous processes appear to be comparably longer for unguligrade quadrupeds than they are for digitigrade and plantigrade quadrupeds [5]. The tail appear to extend back and then downward for unguligrades and back and then upwards for digitigrades. However, how the joints of the tail should be placed in the animation skeleton is likely to be more dependent on the appearance of the character model than on real life anatomy. Depending on the model the skeleton is to be used for, as well as what kind of motion the animator desires, it might be necessary to add an extra joint to the end of the limb joint chains.
The main difference setting plantigrade quadrupeds apart from the other types of quadrupeds studied seem to be the bending of the spinal column and the rotation of the pelvic. The plantigrade spine curves upwards more than what have been observed in digitigrade and unguligrade quadrupeds and the neck vertebrae lie in straighter alignment with the rest of the spinal column. At least one joint may have to be removed from the end of the limb joint chains in order to easy the rigging process.

However, not a very large range of different animals have been studied in this project, and it is entirely possible that a closer inspection of different animals belonging to the same locomotion category may reveal that the differences mentioned above are not depending on type of locomotion, but instead might be occurring in different animals regardless of locomotion.

No testing has been done in order to uncover how the neck, spine and tail of any of the skeletons will work with Inverse Kinematics. Possibly it would be profitable to remove a joint from the neck for both the digitigrade and plantigrade skeletons as well as add a joint to the back of the plantigrade.

4.2 Animation

While the animation skeletons are supposed to be fully rigged, bound and animated
eventually, no animation has been tested with the reconstructed animation skeleton at the point in time when this report is being compiled.

4.2.1 Early FK Based Animation Test

Before the creation of the animation skeletons presented in the previous section, some simple animation tests were assembled in order to better understand how the differences in skeletal structure between plantigrades, digitigrades and unguligrades would effect animation. This test was also carried out in order to see how the different skeleton structures would respond to being animated by applying the same rotational values to corresponding joints. For this early experiment, three different examples of pelvic limb joint chains were created. One was unguligrade (horse) and one digitigrade (dog). The third one was a plantigrade, and was set up based on human anatomy rather than being referenced on a quadruped. This was done for comparison reasons and to allow for better assessment of the accuracy of motion. The unguligrade joint chain was the first to be animated, this being accomplished by using references of the movements of a horse skeleton [5]. After this first animation was completed, the other two joint chains were animated by applying the rotational values derived from the unguligrade limb to the corresponding joints of the plantigrade and digitigrade limbs. Figures 18 through 23 below shows the resulting animation cycle:

Figure 18. Test stride of digitigrade, plantigrade and unguligrade pelvic limbs at frame 1.
Figure 19. Test stride of digitigrade, plantigrade and unguligrade pelvic limbs at frame 20.

Already this early in the stride, it is becoming apparent that the plantigrade limb is not displaying correct deformations. The phalanges are already bending too much.

Figure 20. Test stride of digitigrade, plantigrade and unguligrade pelvic limbs at frame 40.

In addition to the inadequately bent phalanges of the plantigrade limb, the knee is now also in an unfortunate position. The same is true for the digitigrade limb.
Figure 21. Test stride of digitigrade, plantigrade and unguligrade pelvic limbs at frame 60.

Figure 22. Test stride of digitigrade, plantigrade and unguligrade pelvic limbs at frame 80.
While the animation of the digitigrade limb looks plausible though is not without areas of concern, it is overly obvious that the plantigrade limb is not performing in a desirable manner. The phalanges do not bend in a realistic manner, and the knee ends up being too high up.

4.2.2 Inverse Kinematics

Although it is possible to animate solely with Forward Kinematics, it is not practical, and rarely done. Instead animation skeletons are usually set up with Inverse Kinematics [16]. Though no full IK setup has been created for this particular animation skeleton yet, it has been tested with a reverse foot function [16] in order to see how the limbs, and then foremost the carpal/tarsal and metacarpal/metatarsal regions, functions with IK. Below is a series of images, Figures 24 through 28, showing the acquired results:
Figure 24. The digitigrade skeleton with reverse foot.

Figure 25. Functionality of the pelvic limb.
Figure 26. Functionality of the pelvic limb.

The pelvic limb is displaying especially good results when being pulled backwards.

Figure 27. Functionality of the thoracic limb.
While the pelvic limb is showing nice results, the thoracic limb is not optimal. The performance of the thoracic limb may possibly be improved by repositioning the carpal and metacarpal joints slightly.

5 Discussion and Conclusion

During the course if this project quadrupeds have been studied with a focus on both animation and anatomy. Animation history with a focus on animals has been briefly outlined and different approaches to quadruped animation and quadruped animation skeleton creation have been presented. Main advantages as well as disadvantages of these approaches have been stated, as well as the pros and cons of animation techniques such as rotoscoping and motion capture. Additionally, quadruped anatomy and locomotion has been covered in detail and the findings from this part of the report have been utilised in an attempt to construct a generic animation skeleton structure to use with all types of quadrupeds. Quadruped anatomy has also been used in order to better understand the results of the experimentation with anatomically based and adaptable animation skeletons. Below, the content of this report is discussed more throughout.

While quadrupeds are common in 3D animation they do not seem to be as well
documented in regards to 3D as bipeds are. While there are several fundamental 3D handbooks that thoroughly go through the modelling, rigging and animation of human characters, the same thing seem comparatively rare for quadrupeds. Although to be non-discriminatory, non-humanoid biped characters do not appear to be well covered either. There might be a simple reason for this: Human characters are just that, human. Although there certainly are vast variations between humans in real life (body type, gender, ethnicity, physical shape and so on) the internal structures, the skeleton in this case, which govern motion are largely the same, and all humans normally adopt plantigrade locomotion. As such, a handbook outlining the process of creating a human character will readily be able to be applied to pretty much all human characters, and by extension to many other biped characters that adopt plantigrade locomotion as well. When it comes to animals though, a guide relating to one kind of animal will likely not be applicable to all types of animal characters. Chances are that a guide for setting up an animation rig for one type of quadruped will be confusing if applied to another type of quadruped, simply on account of the variations in quadruped anatomy.

Arguably, it could be said that the anatomical variations between quadrupeds are the main reason the creation of quadruped animation skeletons is so complicated. However, it could also be argued that the problem lies nowhere near anatomy, which would mean the solution is not going to be found by studying anatomy either, but rather is an effect of how there are just so very many approaches to rigging in general. Although, if this was the case, would not the same be true for human rigging as well? It probably should, but this does not appear to be the case. It then seems reasonable to believe that quadruped anatomy and the vast differences between quadrupeds are contributing additional difficulties to rigging, which is already considered a complicated part of 3D animation.

Overall, there is no set approach to rigging, no one method that is the only way to correctly set up an animation skeleton for either human or animal characters. And as such, it is hard to know what methods, if any, are wrong. There are technical requirements relating to the tools used for the rigging process, and rules that should be obeyed in order for animation skeletons to function correctly, but the exact process as well as the resulting rig is governed by preferences rather than anything else. For inexperienced users, and oft for expert artists too, the rigging process is very much a
Just as there are different approaches to rigging for animation, there also are different approaches to recreating motion of real life creatures in general. Some methods are more technical than others: Rotoscopying and motion capture both rely on motion first being recorded in order to apply it to character animation and both have a drawback in that only actually attainable motions can be captured. If motions not recordable are required further work is needed. A more suitable approach for quadruped character animation is arguably to study, and apply knowledge of, quadruped movements to animations done by hand.

This same idea could be applied to anatomically based animation skeleton setup as well. In actuality, all animation skeletons are anatomically based. This is the simple effect of wanting to recreate real life motion; one also recreates the anatomical structures that motion stem from. Recreation, however, is not the same as duplicating. Most animation skeletons are not anatomically correct down to the joint, actually one would probably be hard put to find even one such skeleton. Rather, animation skeletons are inspired by their real life counterparts, but then redesigned to suit preferences and to comply with technical solutions. As with anything that is getting computed, animation skeletons should be optimized. Likewise, they should be created to be as easy to work with as possible. If this then means they no longer are anatomically correct down to the bolt, then so be it. As with any creative process, getting constrained because of an idea one is unwilling to drop, even though it might prove unpractical, is precarious. Similarly, getting too caught up on real life anatomy is probably not profitable when it comes to constructing animation skeletons.

Although it might be initially confusing and require more time spent thinking, testing, and retesting than a standardised approach to quadruped animation skeleton structures would, it ultimately seems more productive to approach every new project with a fresh eye and rig one’s character based on the requirements of the project. Likely no one has ever claimed rigging to be a simple or straight forward process, rather the opposite, and as such there is no wonder there are so many different approaches to it. It seems clear this is the way it should be. Letting individuals experiment does not only provide the opportunity for them to discover their own style and their own preferences, but also encourages new creative solutions to be explored.
Sure, it would be practical if there were a method, automatic or otherwise, that would produce fail safe animation rigs every time it was utilised, but somehow that would also take away part of the creative appeal of rigging.

While it may be possible to construct an generic quadruped animation skeleton structure which can be adapted to suit plantigrade, digitigrade or unguligrade quadrupeds alike, the results of this particular project fail to provide any outstanding reasons as to why one would want to do so. The advantages this would bring, mainly recollection of bones and joint, are outweighed by the arising problems of joints being either abundant or redundant depending on what type of quadruped the skeleton is intended for. One would probably have to create an automated application for it to be profitable, and then one faces the possibility that the resulting application will not appeal to some animators due purely to personal preferences.

The three final animation skeletons created for this project clearly show the impracticality of trying to make the same skeleton structure work for different types of quadrupeds. While it might be pleasant to know the exact number of joints to include when first making the skeleton, it will probably not be as agreeable later on in the rigging process. Including additional joints just for the recognition factor is not a good idea, as they are likely to cause problems later on. As have been mentioned above, a far better approach is to consider every character individually and create the animation skeleton based on functionality rather than on anything else. Additionally, the early FK animation test carried out as part of this project suggests that it would be impractical to use the same animation algorithm for animating quadrupeds of different locomotion, and it also manages to show just how unnecessary some joints are in certain animation skeletons.

In conclusion, the idea of anatomically based animation skeletons is somewhat superfluous, as most animation skeletons are anatomically based to some extent anyways. There is no need to take this approach to extremes. A better approach to animation skeletons for quadrupeds are to set them up depending on what one wants them to do; how one want the character to move and how one want to be able to control the character. 3D animation, including animation skeleton setup, is a creative process, and all creative processes involve learning by doing.
Lastly, if one is just starting out with quadrupeds in 3D, the best way to go about it is probably to experiment, go through the trial and error process again and again and hopefully one will become more and more sovereign for every time.

5.1 Further Research

The final digitigrade animation skeleton is intended to be fully rigged for animation with Inverse Kinematics and eventually used for animating a suitable 3D character. Before this can be done more experimentation is required in order to continue the exploration of the functionality of the added tarsal joints of the pelvic limb as well as finding a suitable solution for the thoracic limb.

Eventually the research presented in this report may be used as a stepping stone for beginning to develop a semi-automatic method for constructing quadruped animation skeletons.

The increased availability of motion capture systems for smaller studios, as well as for independent artists, combined with the arising possibility to utilize motion capture without the need for markers may open up motion capture to be more readily applied to animals in the near future. While it is doubtful that motion capture will ever be used for animal character animation there might be other areas of 3D graphics where it could prove profitable to be able to capture animal motion using this technique. It could certainly prove to be an interesting area of study.
References

[Mars 24, 2011].


