# Anatomically Correct Animation of a Humanoid

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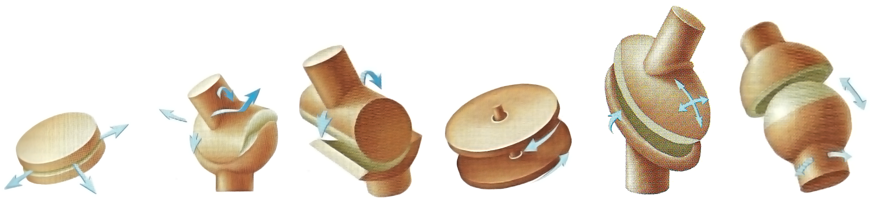
**Resumo**

The human body is one of the most mysterious and fascinating works that nature has ever created. One of the most important requirements for its correct simulation is the animation of its virtual skeleton. It thus becomes useful to be able to ensure that the animations meet the biomechanical constraints of the human body, with minimal recourse to human assistance. We studied several existing techniques of adaptation of animations to skeletons, limitation of rotations in joints with various degrees of freedom, and coupling of motion of joints that in the human skeleton also move together. We developed a model for a skeleton with integrated biomechanical constraints, and indirect driving of some joints. We examined the adequacy of the chosen techniques, pointing out some flaws that currently prevent the proper use of the skeleton and also proposing solutions for them.

## 1 Introduction

In 350 b.c, Aristoteles wrote one of the first documents about the movement of animals [1], but it was Giovanni Alfonso Borelli who in 1680 became the father of biomechanics [2]. Even before Borelli, Leonardo da Vinci had already studied and designed the human body from the anatomical point of view [3]. Initially represented in painting, the human body, and in particular its skeleton, takes form in sculpture, and more recently, digital sculpture in the form of 3D modeling, which is often used in areas of biomedical research, art and entertainment. From the union of these areas arises the need for a skeleton, anatomically correct in composition and movement, which is appropriate to the clinical context and is presented both aesthetically pleasing and credible for several application areas - *from multimedia to interactive characters.* We formulated as the central goal of this work to develop a virtual human skeleton, with anatomically correct biomechanical constraints, implemented in the OpenGL platform, capable



(a) Planar (b) Sattle (c) Hinge (d) Cylindrical (e) Elyptic (f) Spherical

Figura 1: Joint types [4]

of being animating with data synthesized from motion capture and relating to the joints of a humanoid as specified by ISO H Anim-200X[1]. With our work, we present an organized study on humanoid animation, and the incorporation of constraints on their movement. We also propose a general joints model that we used to animate a skeleton with 231 degrees of freedom, including the various methods used to implement biomechanical constraints and also a way to use these methods together.

This document is structured into six main sections. The first (and current) introduces the context and identifies the problem that we address together with the objectives we set, of which the resolution serves as a contribution to the scientific community. In the second and third sections we explore different areas of work that relate to ours, from concepts of anatomy to the animation of human figures. The forth section explains our approach to the problem, containing the architecture of our solution, some considerations that we had, and the model of joints and constraints that we propose to use. In the fifth section we talk about the aspects that had to be tested and analyze the test results, identifying the successes and failures and proposing alternatives. Finally the last section describes our conclusions and future steps.

## 2 Background

On building an anatomically correct virtual skeleton, it is necessary to study and identify the kinematic capabilities of various joints of the real human body. This study relies on data from arthrokinematics. First we must identify the joints whose range of motion will be subject to constraints. Secondly, we must define the types of movement that the joints can execute, and quantify each.

In our work, we considered the *Planar*, *Sattle*, *Hinge*, *Cylindrical*, *Elyptic* and *Spherical* (ball-and-socket) joints [4]. These joints are presented in Figure 1. We consider that the initial pose, in which all degrees of freedom are at zero degrees, corresponds to the anatomical position, *i.e.* a pose in which the

[1] `http://www.h-anim.org/`

skeleton is standing with its feet facing forward, and arms stretched along the body with the palms facing inward.

The knee is usually associated with a cylindrical joint, however, it has a much more complex movement, because the femur slides and rotates on the tibia during flexion and extension. According to [5], the knee swivels over the last 20 degrees of extension, which is enough to have to consider this movement as a coupled motion, *i.e.* the rotation of the knee is a movement that is indirectly driven from its flexion.

The shoulder is one of the most complex joints in terms of body mechanics. The movement, despite being associated with a spherical joint, is in fact associated to three joints, which together are designated as the *shoulder complex*.

The scapulo-humeral rhythm corresponds to the way all these joints work together to allow all possible movements of the shoulder. [5] says that the first 30 degrees of shoulder movement (flexion or abduction of the arm) are performed exclusively in the *glenohumeral* joint. After that, for each 2 degrees of flexion or abduction of the arm, the scapula rotates 1 degree in the same direction. The distribution of the values for each rotation of the vertebrae of the spine depends on the area to which the given vertebra belongs, and in some cases, depends specifically on the vertebra. As [5] explains, the mobile portion of the spine is divided into three sections: the *Cervial*, *Thoracic* and *Lumbar* sections. In this kind of a study it is important to analyze in detail the freedom of movement of the spine, for which [6] is an important reference.

## 3 Related Work

For our work, we examined various methods and techniques of skeleton animation, and ways of controlling this animation. One approach that has emerged in recent years is the incorporation of movement constraints in the joints themselves, and that is also the context that we include our work. [7] delivers information and techniques for representing orientation of joints using quaternions and euler angles, and about using matrices for limiting joint rotations. [8] presents a method for decomposing movement of a ball-and-socket joint in two independent movements: *swing* and *twist*. [9] presents a joint model for the real-time simulation of the joints of the human skeleton in an anatomically correct way. Each joint is a composition of one or more DOFs, and each DOF has its own type of movement, rotational axis and range of possible values. [10] explores several types of constratins between two segments using quaternions. [11] developed a general joint model capable of exhibiting complex movement in articulated figures, which allows non-orthogonal axis of rotation, translation of the center-of-rotation and also coupling of parameters between different joints. [12] show a simple way of using an animation stored in a BVH file to animate a skeleton using *OpenGL*, following the *H-Anim* standard, using quaternions. [13] compared the usage of quaternions or euler angles on animating a skeleton in the *H-Anim* standard. [14] presents a now kind of joints, called spline joints[2],

[2]A spline is a parametric curve mathematically defined by one or more control points.

which follow a more biologically correct approach to the joints of the skeleton.

### 3.1 Skeleton Morphology Adaptation

To address the problem of adapting an animation so that it can be applied to a skeleton with different morphology, we decided to follow the method proposed by [15]. This method uses an intermediary skeleton to adapt the animation. This intermediary skeleton has the same morphology as the final skeleton to which the animation should be applied, however, each joint is oriented following the initial orientation of the animation's skeleton. Figure 2 show an example in which the animation skeleton, designated as *Performer*, possesses more articulations that the final skeleton, designated as *End User*.

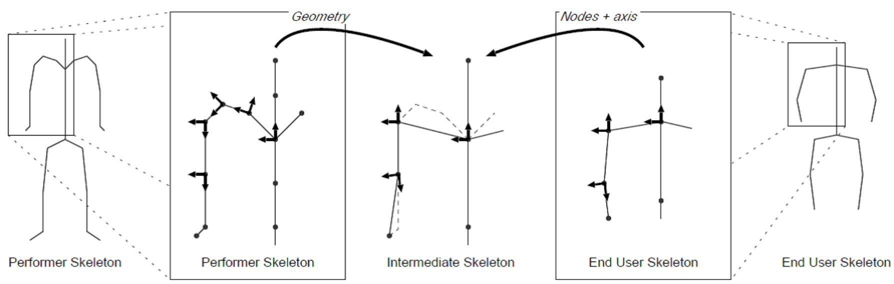



Figura 2: Monzani's Skeleton Morphology Adaptation [15]

## 4 Architecture

### 4.1 General Skeleton Model

We start by defining the general model of the skeleton, in terms of logical structure. Our idea follows the structural skeleton of the *H-Anim* standard, and therefore consists of a set of joints, in which each joint can exhibit some constraint. This constraint results, in turn, of individual constraints applied to one or more degrees of freedom [8, 9]. Figure 3 illustrates our model.

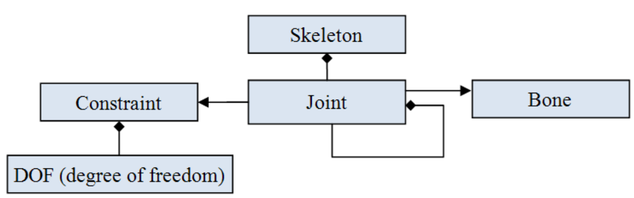



Figura 3: General model proposed for the skeleton.

## 4.2 Joints Model

The joints that we consider follow, in logical terms, a hierarchical structure. There are three basic types of joints: one to simulate joints with only one axis of rotation, other to simulate various axes of rotation, and even a type that does not allow movement, to simulate static joints. All other types of joints are extended from the *Uniaxial* and *Polyaxial* joints, as depicted in Figure 4.

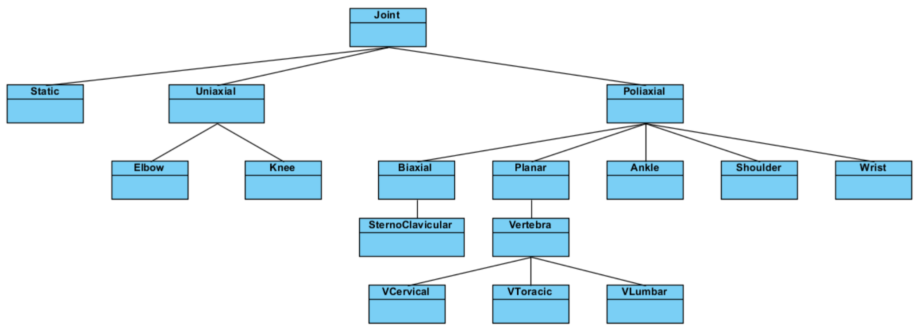



Figura 4: Joints hierarchy used by our skeleton.

The constraints were implemented at the level of the elementary joints, and then the extended joints make use of those routines and calculations. All transformations allowed are numerically limited in each degree of freedom. Every joint has a routine called *Apply*, which receives the rotation matrix that has been applied to the joint, and returns the matrix resulting from the application of its constraint, depending on the type of joint that it is. The following paragraphs describe in more detail some of the joints shown in our model.

**Uniaxial** For the angular constraint on the *Uniaxial* joint, we used the technique of [10]. In this technique, we constrain the movement of one segment against another, to a space defined between two quaternions, *i.e.* the child segment can rotate in it's father's space, according to the axis defined by the transformation of one quaternion to another, between the angles defined by those two quaternions, as is illustrated in Figure 5.

**Junta Poliaxial** Constraints on the *Polyaxial* joints follow the method proposed by [8]. This method separates the motion into two components: *Swing* and *Twist*. This decomposition can be seen in Figure 6.

After decomposing these components, we can limit them independently. Constraining the *Twist* is simple, as we just have to clamp the value between a maximum and minimum angle. To limit the *Swing* component, we use the method presented by the same authors, which is to defining the valid Swing region through a spherical polygon, as shown in Figure 7.

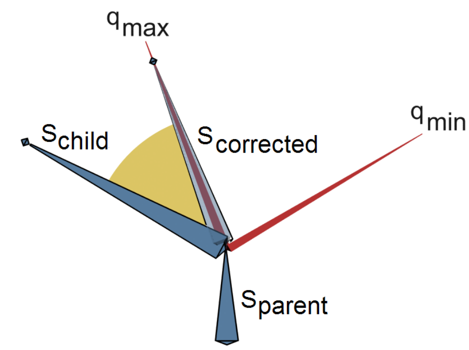



Figura 5: Uniaxial joint correction [10].

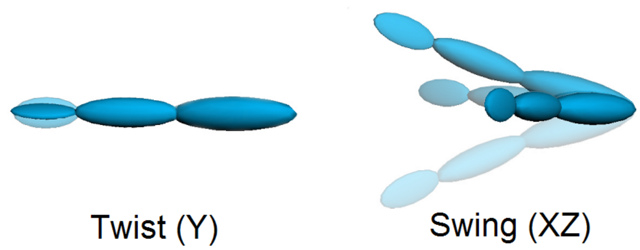



Figura 6: Swing and Twist components of a rotation [8].

**Knee and Ankle (Uniaxial)** The *Knee* joint allows to simulate the passive motion of rotation in the knee. After calculating the final angle, it is used as a parameter for the internal rotation of the knee. The idea of using one degree of freedom to move another, is an idea presented in [11], which addresses various aspects of dependence and coupling between degrees of freedom of the same or different joints. The same technique is used in the *Ankle* joint, which in the real body, couples the movement of flexion with pronation and supination.

**Biaxial (Poliaxial)** The *Biaxial* joint possesses only a *Swing* component, *i.e.* does not allow Twist. Thus, we extend the *Polyaxial* joint, removing its *Twist* component.

**Shoulder (Poliaxial)** To simulate scapulo-humeral rhythm, we follow the approach of [16]. To use this method, we decompose the rotation of the shoulder into elevation and abduction components. These components are better understood in Figure 8. The same paper presents an algorithm that, given the parameters of elevation and abduction that are meant to be applied to the shoulder as a whole, distributes them by the gleno-humeral joint and the sterno-clavicular joint in order to adequately simulate the scapulo-humeral rhythm.

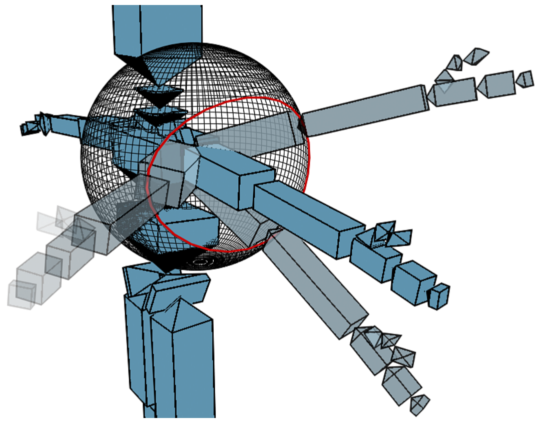


Figura 7: Spherical polygon used for constraining the Swing on the Poliaxial joint [8].

**Vertebra (Planar)** Several authors have addressed the problem of propagating motion through the spine [17, 18]. However, we follow the method proposed in [11] which was previously mentioned. They propose that instead of animating directly each vertebrae, one should animate each of the sections (*Cervical*, *Thoracic* and *Lumbar*). When a vertebra receives direct animation, it conveys this motion to the entire section, so that it can then properly distribute it through all vertebrae that compose such section. This creates a relationship of many-to-one, when several vertebrae animate a section. Then, in a relation of one-to-many, each section correctly distributes the animation through several vertebrae. Doing this enables us to apply the angle constraints to just each of the three sections.

## 5 Evaluation

In a preliminary evaluation, the development team observes the simulation results, comparing it with the expected results, in order to decide if the solution is strong enough to evaluate with users, or if it still needs refinement. By direct observation, we understand that there are several points that need to be corrected before proceeding with the evaluation by users. The reason for this is that the simulation of a humanoid has a big problem in itself, with regard to its perceptual evaluation: the human being can very easily recognize the movement of another human being, which makes it easy to recognize movement that does not correspond to the one of a human being. In our case, we observed an immediate set of problems that need to be corrected: The feet slip on the floor due to a phenomenon known as *footskate* [19]; The elbow is constantly interpenetrating the torso [20]; There abrupt movements because we do not consider history (space-time) in our approach. With all these factors preventing

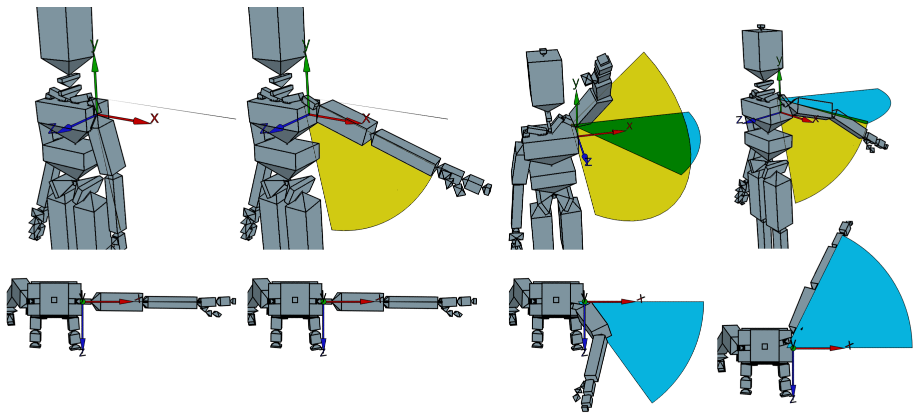


Figura 8: Decomposition of the shoulder rotation into elevation and abduction components [16].

a simulation that could plausibly be considered perceptually correct, we decided not to proceed with the evaluation phase with users, because we know *a priori* that the result of such evaluation would be negative, so running it would be an unnecessary waste of resources and time. These problems are also relevant for the anatomical evaluation of the solution. However, we know some techniques that would better validate the anatomical perfection of the solution. One such technique is the use of spline joints, proposed by [14], which allows the bones to not rotate around an axis, but a surface. In the shoulder complex, we know that we do not have an anatomically perfect solution, since the approach we follow [16] uses only two joints to the scapulo-humeral rhythm , when the right thing would be to use at least three. To improve the anatomical perfection in this zone, we could follow the proposal of [11], which uses a single degree of freedom to simultaneously control the three joints of the shoulder complex. We also did not consider that in the real skeleton, the axes of rotation are not always fixed [9]. The performance of our solution was the aspect that we could evaluate the most. We tried several cases with 16 simultaneous skeletons, each with 231 DOF. The metrics that we considered were: mean time to update each skeleton, and average speed in FPS that the animations were executed. The tested animation contains 481 frames at 30 FPS. Simulation without constraints, had an average of 3.1 ms for the update time, which increased to only 3.25 ms when the constraints were calculated. The average speed of the animation was around 22 FPS in both cases, which revealed that even in the most simple case, our prototype was not keeping the 30 FPS of the animation. However, such speed did not suffer with the calculation of the constraints, showing that they have little impact in performance.

## 6 Conclusions and Future Work

One of the biggest challenges we faced was to combine different techniques proposed by different authors on different coordinate systems and animation parameters. It was necessary to find a common ground for all these techniques, so that we could carry out conversions of parameters in a transparent and efficient way. This common ground was largely built on foundations of algebra and math, and aided by a flexible formulation of computer engineering which was capable of supporting the structures and relationships that we needed. It is also important to develop a good evaluation model for a solution of this kind. It becomes difficult to realize what movement is right or wrong, and it is not easy to establish measures for a correct evaluation of the solutions to this problem. An inspiring case of multimodal evaluation that we analysed was [9]. We end with the feeling that while much has been done, there is still more that we can do. We have not completed the work with a perfect and finished product, however, the study that we elaborated and documented, is worthy of being delivered to the scientific community for others to take further steps on this challenge.

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