

# Biped Animation Using Mathematical Expressions in Maya

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## Abstract

This paper introduces the basics in animation of biped characters using mathematical expressions. It explains the topology of biped character skeleton with advanced legs, characteristic of the movement, basics of driving the parts of the skeleton using cyclic mathematical expressions and finally presents skeleton script user interface. It is an extract of master thesis focused on animation of biped and quadruped characters.

This work is an extension of basic ideas of expression based character animation given by Federico Cascinelli [1]. An advanced skeleton rig and appropriate user interface has been made, so it can be easily implemented in Maya software, product of Alias|Wavefront. Fine tuning of the legs and shoulders has been done, to give more natural looking walk.

**Keywords:** biped, skeleton, character animation, character rig, (IK, FK) inverse and forward kinematics, position and orientation constrains

## 1. Introduction

Character animation is becoming very popular in the different branches of entertainment, mostly game, movie, advertisement industries etc. It is used to breath life onto virtual computer character, to make it act like a human and to impress the wide range of viewers. There is lot of commercial modeling and animation software, which uses different kinds of character skeletons and rigs for animated characters. These not always satisfied the needs of computer animator and this is the reason why the animators building-up their own character skeletons and rigs.

A technique of expression based animation is used to animate real-time game characters. This is data saving, because there is no need to save all frames of the animation, but just the parameters.

## 2. Character Rig

A humanoid character skeleton is too hard to animate by manual keyframing every control. Character rig is used to achieve more efficiency using IK, FK, position and orientation constrains. Some commercial software

uses built-in characters rigs for e.g. 3D Studio Max Character Studio and Softimage XSI, but they do not always giving us sufficient freedom for animation of all parts.

## 2.1 Skeleton

One of the most powerful ways of animating characters is by using skeletons. This part shows a basic skeleton hierarchy, which can be used to animate biped characters.

### 2.1.1 Skeleton by h-anim

One of the normalized skeletal description has been done by h-anim group, it is build up of 89 joints. For a detailed description see reference [2].

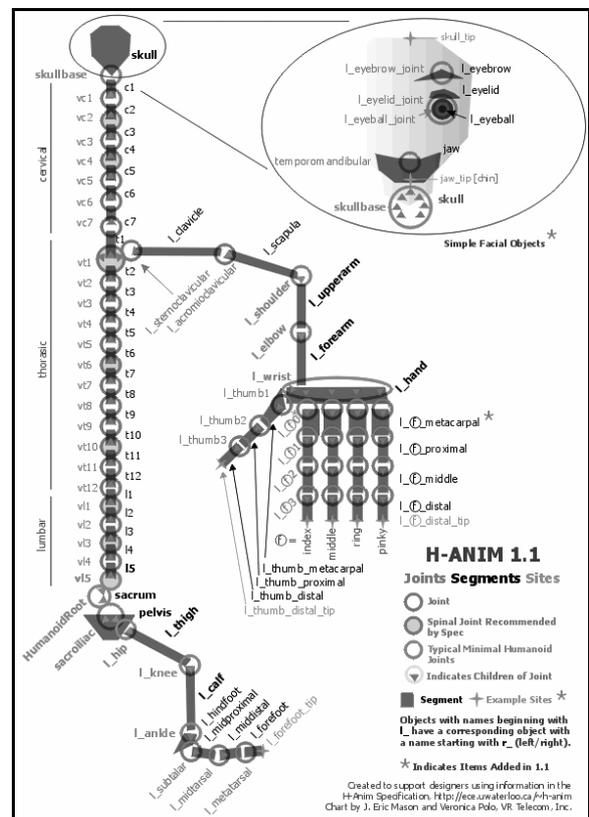


Figure 1: H-anim topology [2]

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## 2.1.2 Skeleton

This Skeleton is also based on human body topology. It is build up of number parts such as spine and head, a pair of legs situated at the bottom, a pair of arms connected at the top of the spine and hands at the end of arms. Legs, arms and spine are controlled by inverse kinematics, which gives the freedom to position the IK goal. The advanced leg and the hand will be analyzed closer. This character rig has been inspired by many rigs seen on Internet, it consists of 70 + 8 (helper) joints.

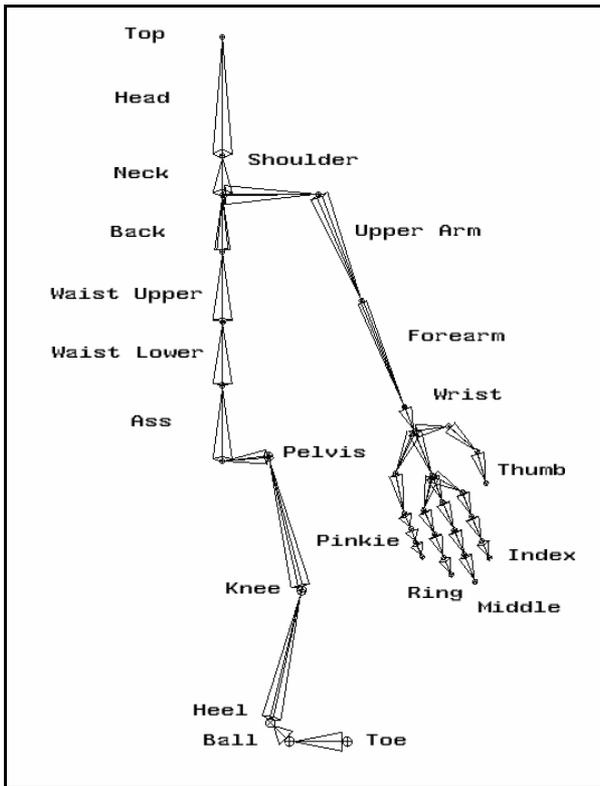


Figure 2: Skeleton

## 2.2 Leg

The leg is the most difficult part of the skeleton. It has to work fine with the smallest number of controlling objects. Different kinds of leg setups can be useful for different purposes. The advanced leg is expression driven just by one controller, and one controller gives the angle of the feet. Tree different leg setups and their advantages and disadvantages are analyzed further.

### 2.2.1 Normal Leg

This leg is created of 5 joints namely *Pelvis*->*Knee*->*Heel*->*Ball*->*Toe* created this way. *Pelvis* is used for positioning the whole leg. The *Knee* makes the leg bend using an IK Handle between the *Pelvis* and the *Heel*. *Heel*, *Ball* and *Toe* are responsible for bending, position and orientation of the *Foot*.

IK setup is really easy. Connection between *Pelvis* and *Heel* is done by IK Handle Tool and we

called it *IK\_Leg*. Complex movement of the *Leg* and bending of the *Foot* can be achieved using the normal leg. Main disadvantage is the fixed pelvis.

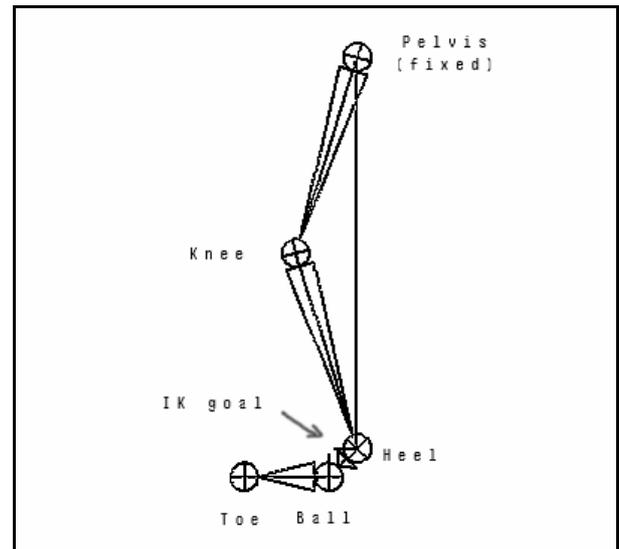


Figure 3: Normal Leg

### 2.2.2 Reverse Leg

Reverse leg contains also 5 joints but the main difference is that the joints are created vice versa *R\_Toe*->*R\_Ball*->*R\_Heel*->*R\_Knee*->*R\_Pelvis*.

IK setup for this leg consists of two IK chains. *RIK\_Leg* IK Handle, which connects the *Pelvis* and *Heel* joint and *RIK\_Ball* IK Handle connecting *Toe* to *Ball*, which gives the rotation around the *Toe* joint. We have a freedom of animating the *Pelvis*, but it is done at the expense of fixed *Foot*.

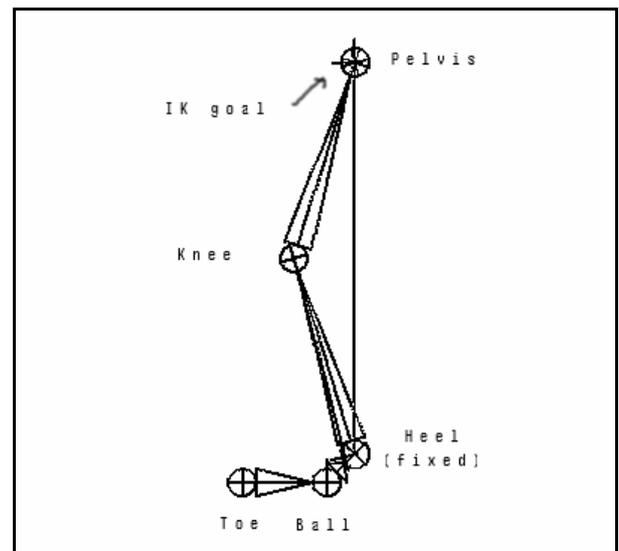


Figure 4: Reverse Leg

### 2.2.3 Advanced Leg

Advanced leg is a reverse leg driven by normal leg. Locators for the normal leg help return the position of the joints. Create locators and point constrain them to *Heel*, *Ball* and *Toe* and call them *L\_Heel*, *L\_Ball* and *L\_Toe*. Connecting of the two legs together is done by two expressions *Const\_Toe* and *Const\_Ball*. Expression *Const\_Toe* constrains the X and Z position of *R\_Toe* to *L\_Toe* locator and the Y position will be always above the XZ plane. The second expression *Const\_Ball* is similar, and it making the bending properly. Solving the contact with the ground first the *Toe* hits the ground, then the *Ball* hits it and last the leg bend properly. Advanced leg is the best and easiest way how to animate the movements of the *Pelvis* and the *Leg*. Bending of the *Foot* is done by the expressions.

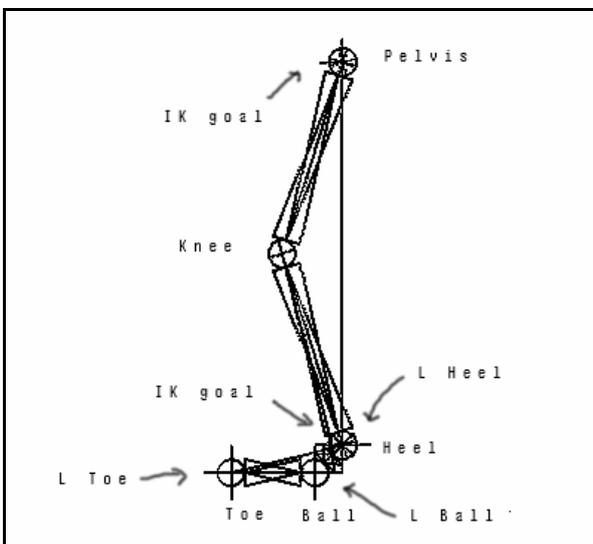


Figure 5: Advanced leg

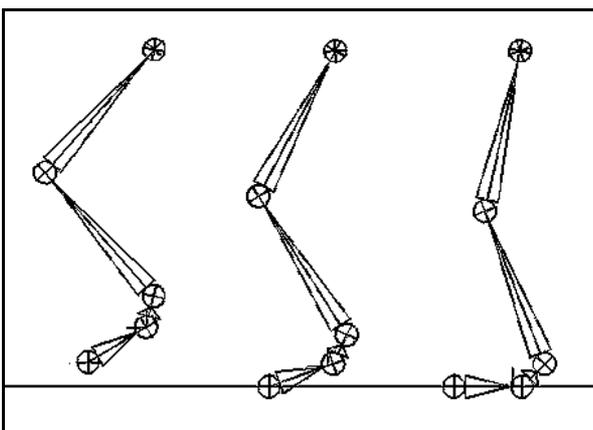


Figure 6: Solving contact with the ground

### 2.3 Hand

The hand is a really complex part of the body. Various movements of the fingers like bending and rotation are implemented in the user interface. Limitation of the joints has been unbroken of course. Control of the hand is completely done by using forward kinematics.

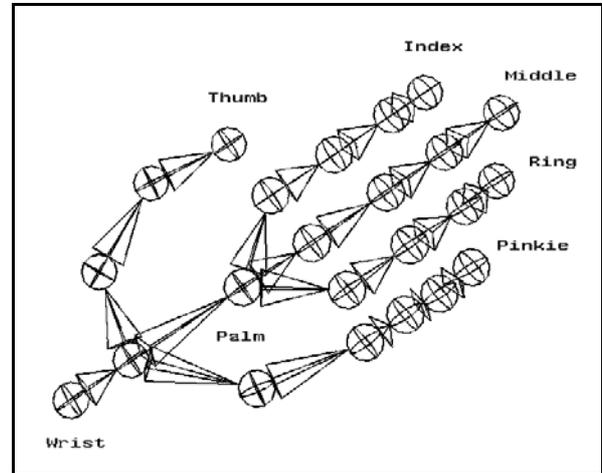


Figure 7: Hand

### 2.4 Difference

Number of joints has been reduced from 89 to 78. There are several differences between my skeleton and h-anim's. The hand setup reduces the number of necessary joints needed to animate the palm. Number of joints of the leg has increased by using a reverse leg, but this result in more freedom of animating the leg. Spine joints have been also reduced, for easier animation. Joints for some facial animation has been totally removed, they are not needed for the purpose of this character.

## 3. Characteristic of the walk

A character's walk conveys a great impression about his personality. Some people waddle, others saunter, and some drag their feet. Almost everyone has a unique walk. Nice example is Charlie Chaplin who had very distinctive walk. If you want to know who a character is, figure out how that character walks.[3]

### 3.1 The Mechanics of Walking

Walking has been described as controlled falling. Every time someone takes a step, actually leans forward and falls slightly, only to be caught by his stretched foot. After a foot touches the ground, the body's weight is transferred to it and the knee bends to absorb the shock. The leg then lifts the body and propels it forward as the opposite leg swings up to catch the body again and this cycle repeats.

### 3.1.1 The Feet and Legs

To keep character looking natural, the joints have to be bent slightly, even at full leg extension. As the weight of the body is transferred to the forward foot, the knee bends to absorb the shock. This is called the *recoil* position and is the lowest point in the walk. The character moves forward, the knee straightens and lifts the body to its highest point, this is called *passing*. The character lifts his foot off the ground, and the body starts to fall forward. The free foot swings forward to meet the ground.

### 3.1.2 The Hips, Spine, and Shoulders

The body's center of gravity is at the hips. During the walk, it is best to think of the hips' motion as two separate. First, the hips rotate along the axis of spine, forward and back with the legs. If the right leg is forward, the right hip is rotated forward. Second, at passing position, the free leg pulls the hip out the center, forcing the hips to rock from side to side. These two motions are transmitted through the spine to the shoulders, which mirror the hips to maintain balance. When the feet are fully extended, the hips rotate along the axis of the spine. To keep balance, the shoulders swing in the opposite direction.

### 3.1.3 The Arms

Unless the character is using his arms, they generally hang loosely at the sides. In this case, they tend to act like pendulums, dragging a few frames behind the hips and shoulders. If the character is running, the arms might pump quite a bit and lead the action by a few frames. Even at full extension, the arms should be slightly bent at the elbows. This keeps them natural.

### 3.1.4 The Head

In a standard walk, the head generally tries to stay level, with the eyes focused on where the character is going. The head then bobs around slightly to stay balanced. The head might also hang low for sad character.

## 4. Expressions

Most of the body parts movements are cyclic so the cyclic goniometric functions are suitable to animate biped characters. Using of mathematical expressions is data saving solution, animation does not need to save all frames, but only parameters for expressions. Characteristic of the movement has been followed as much as possible to keep the walk natural.

This is an example of expression, which drives the movement of the right foot

```
$var           // steps frequency
time          // current time
$rfl          // foot highness
$rff          // foot frequency
$rfl          // foot length
$ho           // hips oscillation
$hh           // hips high
$hp           // hips position
```

```
$ty = 2*sin(time *$var);
$tz = cos(time *$var);
$tsy = sin(time *$var -90);
$bac = $hh + (sin(time *($var *2));
```

*ty* and *tz* gives the transformation in y and z axis, they depends on the *time* and *var*, where *var* changes the period of the sin, cos functions

*tsy* gives the the transformation of *ik\_toe* to fine tune the contact with the ground

*bac* makes the basic movement of the pelvis in y direction

```
if ($ty>=0)
RLeg_foot.translateY = ($ty *$rfl) ;
RLeg_foot.translateZ = (-$tz *$rff) +$rfl);
RLeg_ik_toe.translateY = ($tsy);
CRLeg_pelvis.translateZ = 4*($tz *$ho) -$hp;
CRLeg_pelvis.translateY = $bac - 4*($ty *$ho);
```

if condition fixes the Y-position over the ground  
*rfl*, *rff* and *ho* changes the amplitude of the sin and cos  
*rfl*, *hp* and *bac* positions these functions

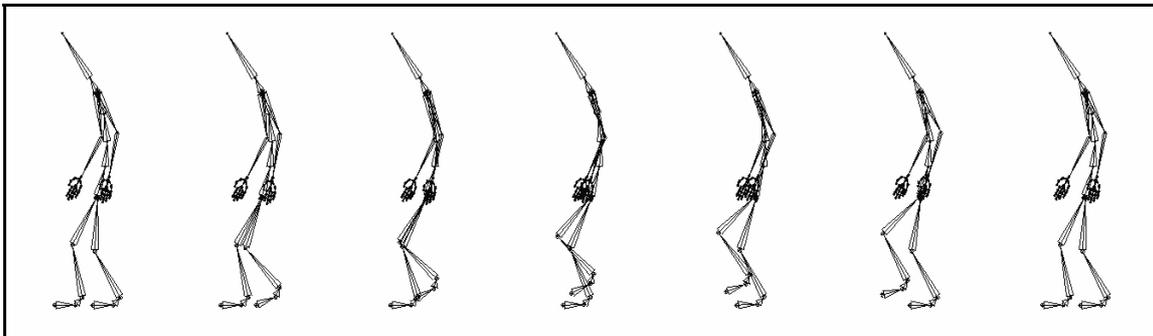


Figure 8: Cyclic walk of the skeleton

## 5. User Interface

Skeleton's user interface is used to set the parameters for the expressions. It is divided into several tabs corresponding to different parts and parameters of the skeleton: *Walk*, *RHand*, *LHand*, *RLeg*, *LLeg* and *Info*. The *attrCollection.mel* script has been used to create the user interface. Other advantages of this script with easy keyframing and saving different poses are very useful for animation.

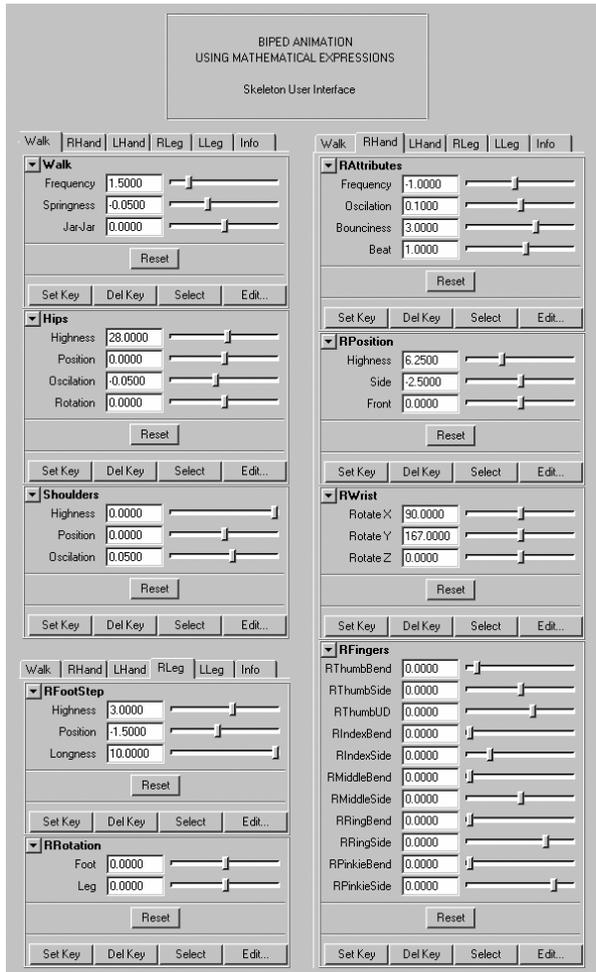


Figure 9: Skeleton User Interface

## 6. Conclusion and Future Work

This paper is a review of skeleton setup for biped characters and basics of animation using mathematical expressions.

An advanced skeleton rig and appropriate user interface has been scripted, so it can be easily implemented in Maya software, product of Alias|Wavefront. Fine tuning of the legs and shoulders has been done, to give more natural looking walk.

Collected knowledge with biped character animation will be used to create quadruped skeleton and evaluate expressions that will animate quadruped characters.

## Acknowledgement

This work has been done by using Maya 4.5 Personal Learning Edition free product of Alias|Wavefront. An unofficial Alias|Wavefront script *attrCollection.mel v1.6 Beta* has been used to create the user interface of the skeleton.

Special Thanks to Federico Cascinelli for many useful ideas and supervising of this work.

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