RIGGING A HORSE AND RIDER: SIMULATING THE PREDICTABLE AND REPETITIVE MOVEMENT OF THE RIDER

A Thesis

by

JENNIFER LYNN KUHNEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Visualization Sciences

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Approved as to style and content by:

Carol LaFayette (Chair of Committee)	John Keyser (Member)
Donald H. House (Member)	Phillip J. Tabb (Head of Department)

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ABSTRACT

Rigging a Horse and Rider: Simulating the Predictable

and Repetitive Movement of the Rider. (December 2003)

Jennifer Lynn Kuhnel, B.S., Texas A&M University

Chair of Advisory Committee: Prof. Carol LaFayette

It is nice to give animators artistic freedom, but having to animate every bounce, sway, and counter-balancing movement of a rider on a horse isn't freedom at all. It is painstaking labor that could easily be prevented with an effective character setup. If an animation piece is only going to have a few shots with a horse and rider, then the trouble of setting up an automated character rig is not practical, but if there are a significant amount of shots with a horse and rider galloping across the prairie, doing death defying stunts, and walking for an extended time into the sunset then there needs to be a way to automate the reactions of the rider to the horse. This thesis focuses on what parts of a horse one can analyze to know at what point a rider will lean forward, bounce up from the saddle, or in any way react to a variety of different horse movements. The automated character setup, or rig, makes animating a rider on a horse much more efficient.

DEDICATION

To my loving family, for always encouraging and supporting me.

ACKNOWLEDGMENTS

I first, thank my committee chair, Carol LaFayette, for her guidance through this project. Her visual sense was a great asset for critiquing the process of my thesis. I also thank my committee members Don House and John Keyser, for their time and feedback. They provided additional ideas to help make the project more complete.

I would like to give a special thanks to Pamela Bruemmer and Tana Rawson, coaches from Texas A&M's Equestrian Team. They were very generous in their time and performed a variety of horse movement for the reference footage used in this thesis. They spent the time to answer questions about the footwork of horses and encouraged me to ask them more questions at any time.

Thanks to Kaushik Paul for the use of his awesome horse model. His visual skills are first rate, and I wish him luck in the future. A special thanks to Jinnah Yu for her friendship and help with my thesis. She is also a very talented person, and I wish her the very best.

As always, my family is the strong base that supports me. Their love shows in everything they do to help guide me through life's rough times. They are the reason I don't ever stop trying and always keep hope for the future.

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1. INTRODUCTION

This thesis focuses on developing a character setup or rig that can simulate the rider's movements and reactions to a horse's movement by just animating the horse. A character setup involves the underlying joints and mechanisms that aid in animating a character for the computer graphics industry [Graft et al. 2002]. Just as a real human and horse have a skeletal system, a computer-generated character also has one made of a series of joints. These joints can be setup and monitored to control the movement of the character. With an efficient character setup or rig for a horse and rider one could automate the balancing, bouncing, leaning forward, or shifting of the rider's center of gravity.

Animating both a horse and human rider is very difficult and time consuming. Although, it is true that rich animation comes from the details we notice and convey through direct control over the animation, the goal of this thesis is to help the animator with repetitive and predictable movements of a rider. Animators can then spend more time on the performance of the character. More attention can be focused on facial expressions or key elements such as important gestures that help communicate the story.

This thesis follows the style and format of *ACM Transactions on Graphics*.

This research path also benefits character Technical Directors by developing a useful way to simulate a rider's movement. The process and developed calculations of this thesis can be expanded to other quadruped and rider movements. According to Michael Ford and Alan Lehman, "Charcter TD's build and create the skeletal and control systems that enable the animator to create and breathe life into a virtual character. Combining artistry, ingenuity, and mechanical know-how, a character TD's skills, rooted in character and creatures, are put together to create effective, efficient, and intuitive character setups." [Ford and Lehman 2002]

Horses are such complicated animals. The power and grace of their beauty is perhaps never to be recreated. One might ask why one would want to animate a horse and rider in the first place. There are several answers to this question. The first would be to achieve the unimaginable: to have a horse leaping over a canyon that would be impossible to conquer yet through great animation one could believe it truly happened. In reality certain stunts on a horse would be too dangerous, but with a computer simulation there is no risk. The second reason is to have complete control over what the horse and rider will do to communicate a story without the cost of using actual horses and trainers. The third reason is to recreate a horse and rider for educational purposes, so by visual means students and researchers can learn the mechanics of their movement.

By breaking down the movement of a horse through observation, biomechanics, and physics one can better understand the movement of the rider and his or her reactions to a horse's gait, jump, or shift in balance. This thesis focuses on developing a useful character setup or rig that helps automate some of these reactions. The researcher defines a useful rig by three attributes: a rig that would have applicability to the graphics industry; a rig that simplifies the task of the animator to create realistic rider motion; a rig that would be easily used in a Maya, a common software program used by industry experts.

2. PROBLEM STATEMENT

There has been much research on a horse and rider’s movement to improve a rider’s skill for real world riding. There has also been research involved in simulating a horse's legged locomotion for the animation of quadrupeds without the rider. Though both forms of research are extensive, there is little available research that involves taking what has been learned about real world riders and trying to simulate it with a set of expressions. There is no accessible and cumulative knowledge base for character TDs to help them recreate the realistic movement of a rider without having to dig deep into research and spend time analyzing reference video. Without actually observing horses or knowing how to ride, a rider's motion can be very difficult to animate. Analysis of different video and research resources provide important attributes that, when defined for a person designing a rig, can be automated to significantly help the animator with the rider's repetitive and predictable movements. From the animation of the horse a set of expressions involving the analysis of a horse’s joint positions can be developed that will automatically drive correct rider movement.

3. BACKGROUND

Simulation of a rider on a horse requires visual reference and research from areas such as animation, education of riding, biomechanics, and robotics. The following summarizes previous work in the study of motion and the computer animation that allows one to simulate it.

3.1 Anatomical Visual References

In the late 1800s, Edweard Muybridge provided an invaluable reference with his stop-motion photographs of animals. In his book *Animals in Motion,* there are sequenced photographs of a horse and rider performing different walks, trots, ambles, gallops, and jumps. Each sequence is unique with a different rider and horse [Muybridge 1957]. Susan Harris educates us with her book, *Horse Gaits, Balance, and Movement.* She goes in to the details of the structure of a horse, how it moves, and how the rider can affect that movement [Harris 1993]. Harris teams up with Peggy Brown in their two videos *The Visible Horse* and *The Visible Rider*. With these videos one can analyze the underlying muscles painted on a horse or the movement of the human bone structure, emphasized by a bone suit worn by the rider [Harris and Brown 2000a; Harris and Brown 2000b]. *The Horse in Motion* discusses the anatomy of a horse and provides visual comparisons of a horse making a jump with and without a rider to stress the compensations a horse makes for the extra weight on his back. The book also breaks down the movement of a walk, canter, trot, gallop, and jump [Pilliner et al. 2002]. Susan Von Dietze in her book, *Balance in Movement, The Seat of the Rider,* focuses more on training one to ride a horse correctly [Dietze 1999].

3.2 Automating Gait Cycles

While references like these are very useful and educational the next step is finding a way to apply what one has learned to animation. Some have paved the way with simulating legged locomotion for quadrupeds. In the PODA animation system, Michael Girad develops animation of multiple legged figures, arguing that positioning of keys for many different joints with several different degrees of freedom is tedious. PODA automates the gait cycle, but allows the user to experiment with different variables to specify a type of gait. PODA generates a support profile that defines which legs are in contact with the ground at each instant. He provides useful information explaining that a gait cycle period consists of foot placement, the support duration, the foot lift off, and the transfer duration. With the equations provided one can calculate the time of each phase [Girard 1986]. Marc Raidbert and Jessica Hodgins later developed control algorithms based on physical models to dynamically control legged locomotion. They strived for similar results to Girard's PODA system, allowing the user to regulate different running speeds, change gaits, and traverse simple paths by using numerical integration of physical models [Raibert and Hodgins 1991]. There are other papers like Nick Torkos' thesis on footprint-based quadruped motion synthesis focusing on automating the gait cycle for quadrupeds [Torkos 1997]. Research such as this provides useful information concerning much of the motion of a rider is reacting to foot impacts of a horse, but the focus of their research does not directly relate to the rider.

3.3 Virtual Reality

Others have tried to simulate the rider in different ways. Youichi Shinomiya, Junji Nomura, YukioYoshida, and Tetsuhiko Kimura used virtual reality to provide horseback riding therapy. By placing a mark on a horse's saddle during actual horseback riding, they recorded the movement of the saddle with high-speed photography, later transferring the movement of the mark to three dimensional data. In this project, they only duplicated the walking of a horse, since that gait had the most curative effects on the patient. The data, a series of curves representing the x, y, and z amplitude and the yaw, pitch, and roll degree of the saddle was applied to a robotic mechanism that one could ride like a horse [Shinomiya et al. 1997].

3.4 Motion Capture

Since this thesis deals with a computer generated rider there should be a way to transfer recorded data to the character. The most common way to do this is through motion capture. This is similar to what was done to capture data for the virtual horseback simulator, but instead "optical, mechanical or magnetic sensors record the movements that can then be transferred to animated characters." [Gleicher 1999] Although motion capture can be very useful for specific situations, according to Michael Gleicher, "the term motion capture is used to describe the whole process. This has the problem that it neglects other aspects of the task, and sets up some unreasonable expectations about how much work needs to be done to move from the sensor data to animation" [Gleicher 1999].

Motion capture data is difficult to work with. Many animators want a way to alter the motion capture for a richer variety of behaviors. Some have been successful. Victor Zordan and Jessica Hodgins found a way to input upper body movement from motion capture and adapt segments for new situations using dynamics. They added a collision handler to provide interactions with the environment. They also added a specialized task controller that can edit character motion at the behavior level in order to correct errors due to kinematic differences between the captured actor and the graphical character [Zordan and Hodgins 1999].

Motion capture can still be expensive in terms of time and resources. According to John Kundert-Gibbs, "Mocap generally shines when used to animate human or anthropomorphic, bipedal characters. In some circumstances, it has been used to realistically re-create the motions of animals" [Kundert-Gibbs 2002]. This suggests that motion capture is not generally used for animals. For the purpose of this research, one would have to capture the motion of the horse and rider at the same time. The only way the rider would look believable is if he or she is reacting to the horse's movements, which are variable. Sensors would have to be put on the horse and the human to capture data for different situations. To create a library of movements, one would have to record many different situations. This seems like a complicated, unnecessary process if one could only figure out what drives the movements of rider. This way one would not have to think of how the rider would react in every situation. From a base set of rules and principles there should be a way to predict what would happen to a rider in any given situation.

3.5 Animation Clips

Another help to the animator is the "trax editor", a nonlinear animation editor that allows one to keyframe a short animation and then record it into a clip to be used again. The clips can easily be replicated, moved on a timeline, and modified for length and speed. One can even blend clips together to create more interesting character animation [Kundert-Gibbs and Lee 2001]. The problem with the trax editor is that the animator still has to create the initial riding movements for each clip. For a jump, gallop cycle, or stop, one has to animate both the horse and rider in each of these situations. This includes all of the rider's bouncing, swaying, or hip motion in addition to the horse's leg movement along with the rider's facial expressions. The rider's movement also has to react to what a horse is doing at the time. One could not just make a clip of one bounce of a rider, replicate it hundreds of times, and blend it with the horse's gallop cycle. First, it probably would not be synchronized and the animator would have to make adjustments for that. Second, it would not be variable and would look repetitive, so the animator would have to make adjustments for that too. All of a sudden much more work is created. The ideal situation for the trax editor is to animate both the horse and rider's movements at the same time so that they are in sync with each other, make a clip of each movement, and then blend and adjust these clips in the timeline. This still doesn't solve the problem of the large library of clips required, in which one still has to animate the rider.

3.6 Expressions

In Maya, a 3D software program widely used by students and industry experts, one has the ability to create expressions to help in the automation of the animation process. Expressions use mathematical functions to relate objects to other objects [Kundert-Gibbs et al. 2001]. By using expressions one can monitor the movement of the horse's joints to influence attributes like the rotation or translation of the rider's joints. One can evaluate the horse's rear rotational hip joint to tell the rider when to counter balance forward, backward, or side-to-side.

This researcher had originally intended to use MEL scripts, which are similar to expressions, to automate the rider. A few differences in the two resulted in the decision to use expressions. The most important reason was by using expressions if one advances in the timeline in a Maya scene, the expressions are evaluated and recalculate the position of the character's joints. Expressions also are usually part of a scene and MEL scripts are usually executed separately from a scene [Wilkins and Kazmier 2003]. For the purpose of this research, expressions are the most effective way to continually monitor the horse's movement and update the rider's reaction.

Using expressions, one doesn't have to use complicated motion capture equipment. The software is easily accessible for students and industry experts. Expressions provide a way to avoid making a library of all types of rider movements. The solution to automating the rider by expressions could be adjusted and applied to other character rig setups in Maya.

4. METHODOLOGY

4.1 Reference Footage

Reference footage was collected from a variety of different sources including movies, horse judging, and horse training videos. The most resourceful reference material was obtained from filming live footage of Texas A&M's equestrian coaches, Tana Rawson and Pamela Bruemmer. They were very helpful in performing several different movements of a horse and rider in both English and Western riding styles.

The most useful stock references were movies including *Monte Walsh* [Winer 2003], *The Black Stallion* [Ballard 1979], and *The Man from Snowy River* [Miller 1982]. The most useful training videos were *The Visible Horse* and *The Visible Rider* [Harris and Brown 2000a; Harris and Brown 2000b]. Different television specials such as, the PBS special on *Horse and Rider* also provided useful reference footage [Simon 2003].

A variety of different horse movements were needed to be able to write the calculations that would prepare the rider for an array of situations. At first, the jump, trot, gallop, stop, and rear defined this range of motion for the rider, but later other movements were added to test the animation in more extreme cases. Section five, of this thesis goes into the details of a horse and rider's movement for the jump, trot, gallop, stop, rear, and a little bronco riding. The analysis of the horse and rider for these various movements comes from research and observation. In section six, general mechanisms, a set of principles summarizes this research and observation so that the researcher has the ability to write a set of expressions that will generate the rider's movement for a variety of different cases.

4.2 Character Setup

A character was setup for both the rider and the horse to be able to develop and test the expressions. The human, character rig was originally created by the researcher with instructions from Michael Ford and Alan Lehman in their book, *Inspired 3D Character Setup* [Ford and Lehman 2002]. The horse rig was originally setup by Kaushik Pal, from Alias|Wavefront's demo DVD, *Maya Techniques | How to Integrate Quadrupeds into a Production Pipeline* [Guidon 2002]. Since the rigs were setup with the advice of these professionals the rigs are a good representation of a character rig one would generally use for a human and horse. Some changes have been made to these rigs to allow for customization, but the basic structure of these rigs are similar. This should ease the transfer of the expressions developed for this research to other industry rigs. More about the horse and rider character setups is explained in section seven.

4.3 Test Animations

To help the researcher determine if the algorithms applied as expressions were working correctly, an animation was set up for each movement, by animating the horse as in the reference source. Then the animation and reference source in the background were played simultaneously to help catch differences in the movement. The set of expressions was applied to the combined horse and rider rig. That same rig was referenced into each animation, so that for all of the different animations of the trot, gallop, stop, rear, and jump one set of expressions simulated the movement for all cases. The trot, gallop, stop, rear, and jump were compared to the reference footage with each update of the expressions, so that the mathematical comparisons could be altered to achieve a better simulation of the rider. A detailed explanation of the calculations developed for the expressions is included in section eight.

4.4 Comparisons

The final animations were compared with the reference footage to gauge the success of the rider's movement. More details of these final animations are discussed in section nine, results and conclusions. Overall, the movement looks very similar. The rider balances well when the horse rears up, stops, and jumps. The rider bounces up and down correctly in the trot and has nice hip motion in the walk and gallop. With the consideration that the researcher is trying to replicate human motion, which is very complex, there are always more variables to be considered for the future. The rider's cloth and hair could be improved and the rider's motion could be a little more fluid.

There are also a few differences that could be caused from the animation of the horse. The reference footage has several different riders and sizes of horses that make it difficult to exactly match the researcher's horse and rider with the referenced horse and rider. But, in spite of those differences it is amazing to see how closely the developed expressions simulate the rider's movement. This research proves that from the animation of the horse a set of expressions involving the analysis of a horse's joint positions can be developed that will automatically drive correct rider movement.

5. HORSE AND RIDER MOVEMENT

There are several different riding styles. Many of these styles depend on the job the horse has to perform and the type of horse that is being ridden. The two most common styles are Western and English riding. According to Susan Harris, “The western horse works with low and efficient strides with little hock and knee flexion.” The rider’s upper body is shifted slightly behind the horse and the rider’s legs are placed slightly in front of the rider’s body. Typical gaits and movement for the western horse are the walk, jog, lope, gallop, and sliding stop. According to Harris, “English pleasure horses and hacks are ridden in a collected balance, which produces smooth, balanced gaits that are easy to ride.” The rider’s upper body will remain straighter, with more poise, riding slightly on the pelvic bone rather than the "butt-bone." Typical movements for the English horse include, the walk, trot, canter, gallop, and jump [Harris 1993].

In an animated film a combination of all of these movements may be desired, even though in reality one horse may not be able to perform all of these movements. What is important is that the overall balance is the same for the two styles. Although, for the purpose of this research, this researcher chose to emulate western style riding, much of what has been developed for the Western style riding can also be applied to the English style. With the development of mathematical expressions that help simulate a jump, trot, gallop, rear, stop, and a little bronco riding, the animator should have freedom to create a variety of motion. To develop the mathematical expressions to simulate the rider, one first has to understand the movement of the horse for each of these cases.

5.1 Jump

There are four stages to the jump: the approach, take-off, flight, landing, and recovery [Harris 1993]. Figure 1 from Pilliner's book, *The Horse in Motion,* demonstrates the movement of just the horse in the jump.

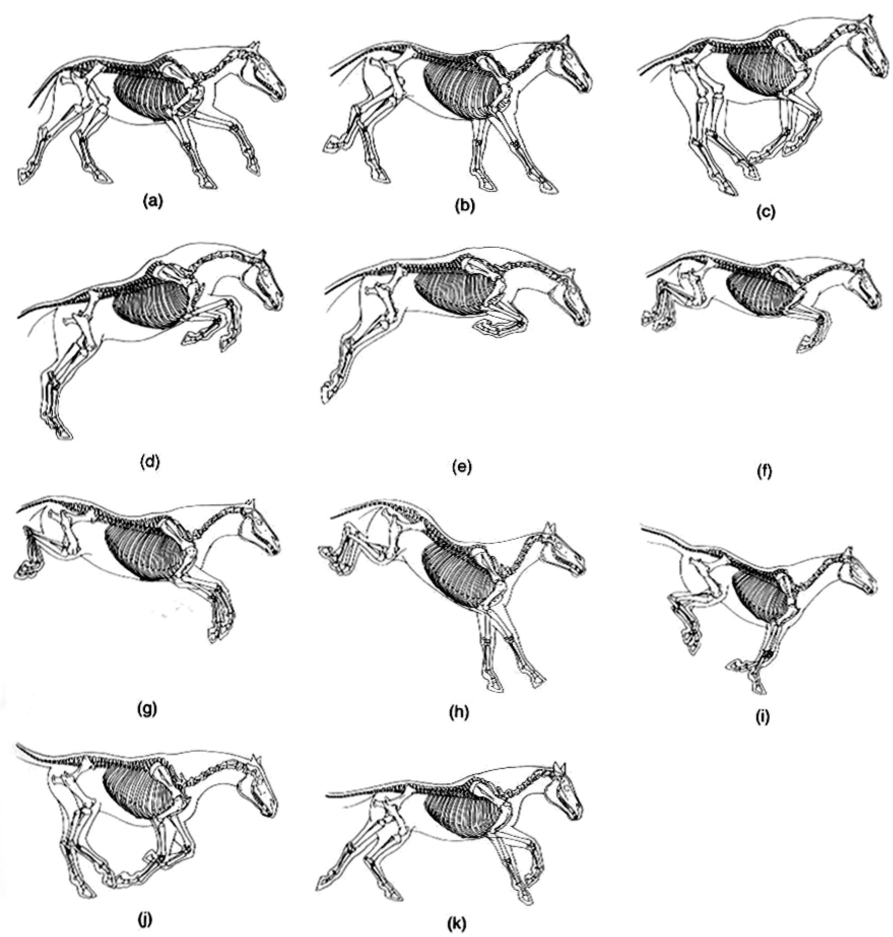

Fig. 1. The jump in motion [Pilliner et al. 2002].

As the horse approaches the jump it judges the height of the object to ascend. The horse plans the closest take-off point and the amount of impulsion needed for the jump to be successful [Harris 1993]. The hindquarters play a significant role in the impulsion. They rotate under the horse's body to support the weight and push off close to the hoof print left by the leading forelimb. According to Pilliner, "The amount the forehand is elevated before take-off influences the trajectory through the air while increased flexion of the hind limbs increases upwards impulsion." [Pilliner et al. 2002]. Through the flight stage, the horse lifts his hind legs up and tucks them under himself to clear the jump. The neck reaches forward to help balance the horse over the obstacle. As the hind legs pass over the hurdle, the horse stretches his back, raises his neck and begins to prepare himself for the landing by unfolding his forelegs. One front foreleg will hit the ground first and then the second foreleg. After landing the horse needs to recover balance. If the jump is executed smoothly balance can be recovered with ease [Harris 1993].

The above describes the movement of the horse in a jump without a rider. The following reference sequence demonstrates this movement along with the rider. In Figure 2, Pamela Bruemmer, English rider and Texas A&M Equestrian Team Assistant Coach, demonstrates the jump beautifully.

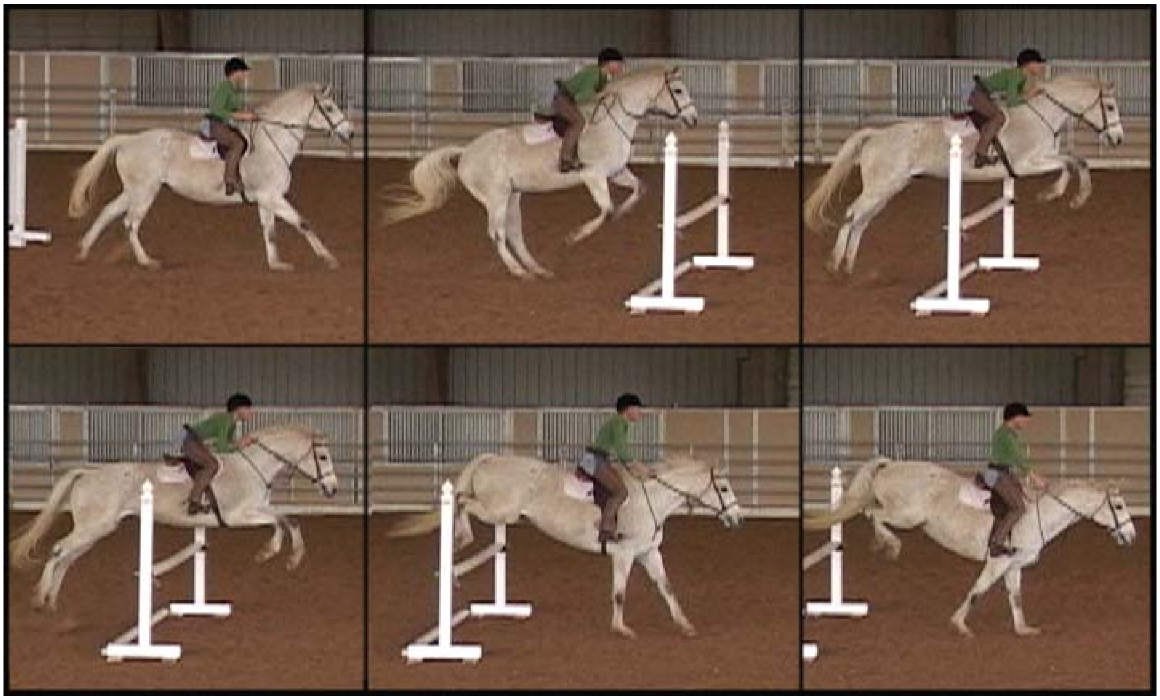

Fig. 2. Pamela Bruemmer's jump sequence.

When analyzing Pamela Bruemmer on the jump, the following motion was observed. As the horse's fore legs lift up for the jump the rider leans forward to compensate for the horse's change in center of gravity. As she leans forward she raises out of the saddle. The rider continues to lean forward as the horse is in midair, directly over the hurdle. The rider starts to lean back as the forelegs reach for the ground and the hind legs are in the air. The rider straightens out her back as the horse's forelegs hit the ground, then the rider bounces bending forward and back down after the impact. Her hands move a little about the horse's neck where she has placed them, but mostly stay in position. As she gets closer to the horse in mid-jump her hands touch the horses neck, where as normally they are close to the neck, but do not rest upon it. Pamela's legs shift back when she leans forward for the jump and shift slightly forward as she sits back in the saddle. Figure 3 shows the entire motion as a photo-montage.

Fig. 3. Pamela Bruemmer's jump in motion.

5.2 Trot

In the trot a set of a front foot and back foot move in unison. The trot is a two-beat foot sequence which means that the each pair of feet strike the ground together for one hoofbeat, then the horse pushes off and is suspended in the air for a moment before the opposite diagonal pair of feet strike for the second beat as in Figure 4.

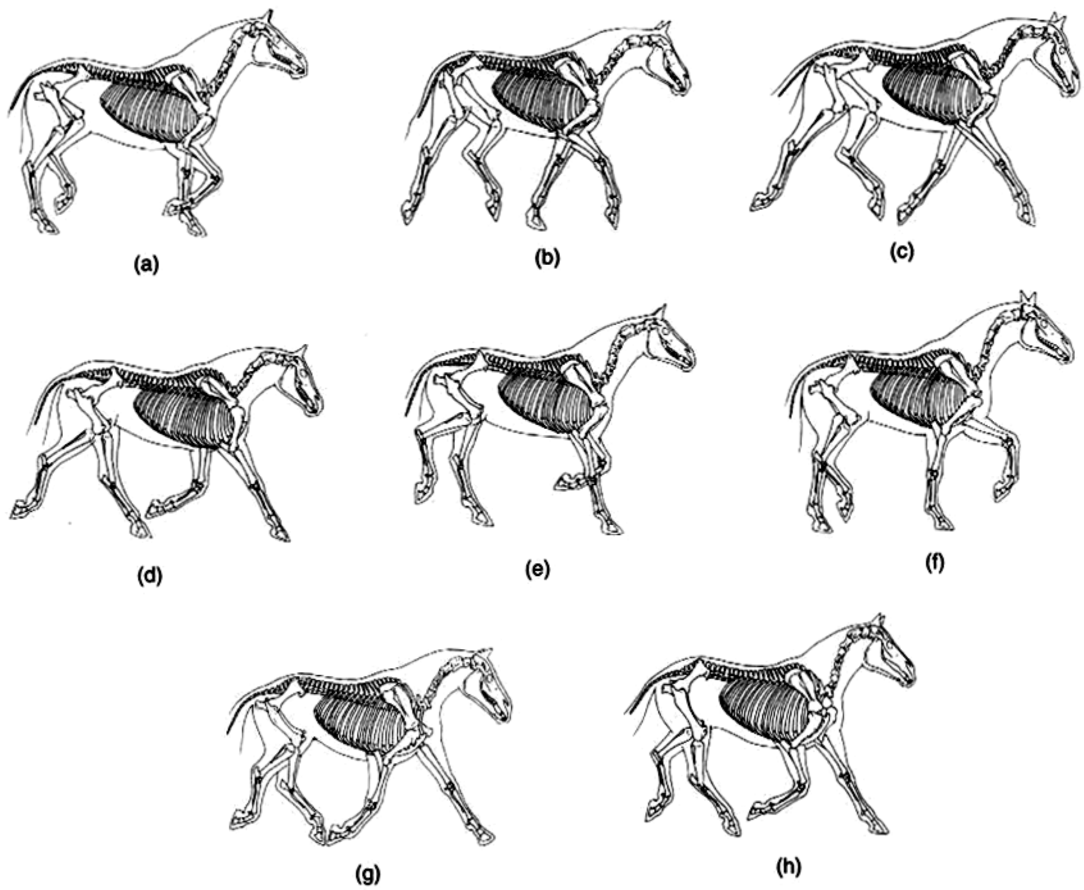

Fig. 4. The trot in motion [Pilliner et al. 2002].

According to Susan Harris, “The sequence is (1) right hind and left fore (suspension), (2) left hind and right fore (suspension). The moment of suspension gives the trot its characteristic spring or bounce.” [Harris 1993]

When analyzing Tana Rawson, a western rider and Texas A&M’s Equestrian Team Head Coach, in the trot, the researcher noticed that much of the rider’s motion is due to the horse’s whole body rising and falling as the horse’s feet move in and out. The movement of the rider is very repetitive. Figure 5 shows how the rider is thrust up as all four legs of the horse are fully extended. The distance between the front and rear legs is the greatest at this point.

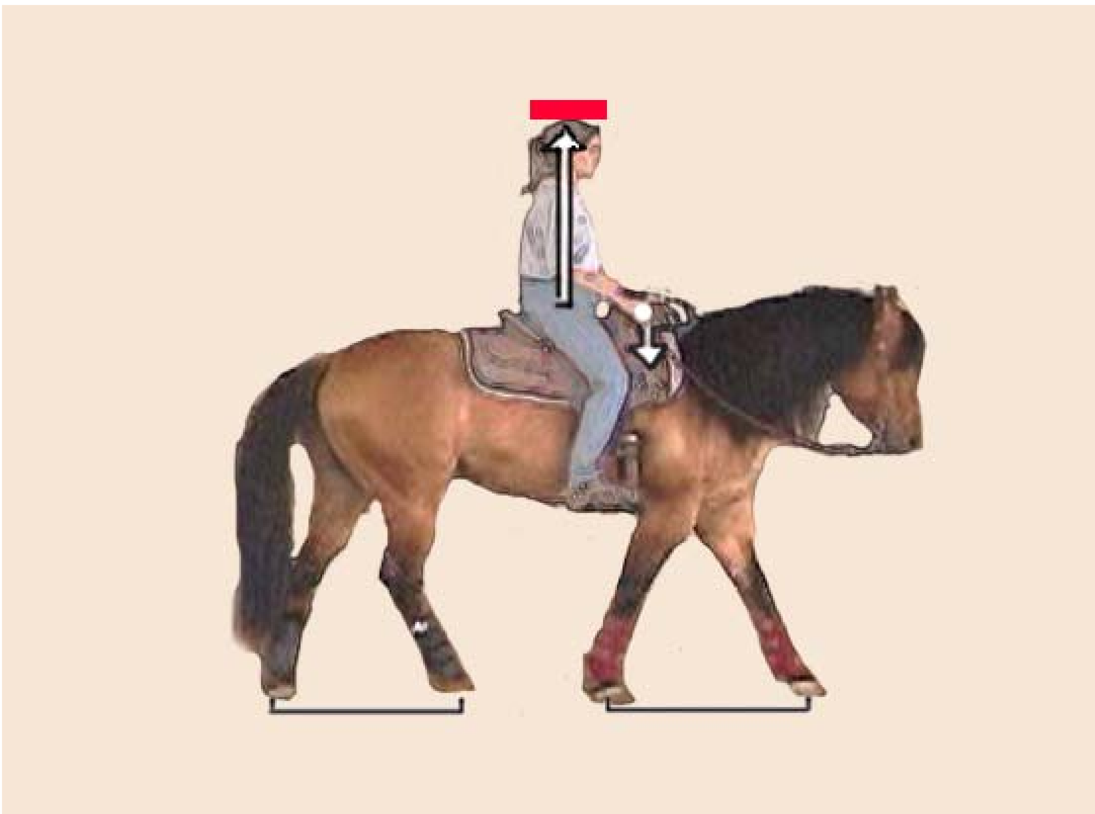

Fig. 5. The rider rises upward.

Figure 6 shows how the rider then sinks back into the saddle as the legs are flexed and are in their transition phase. The distance between the front and rear legs becomes much smaller.

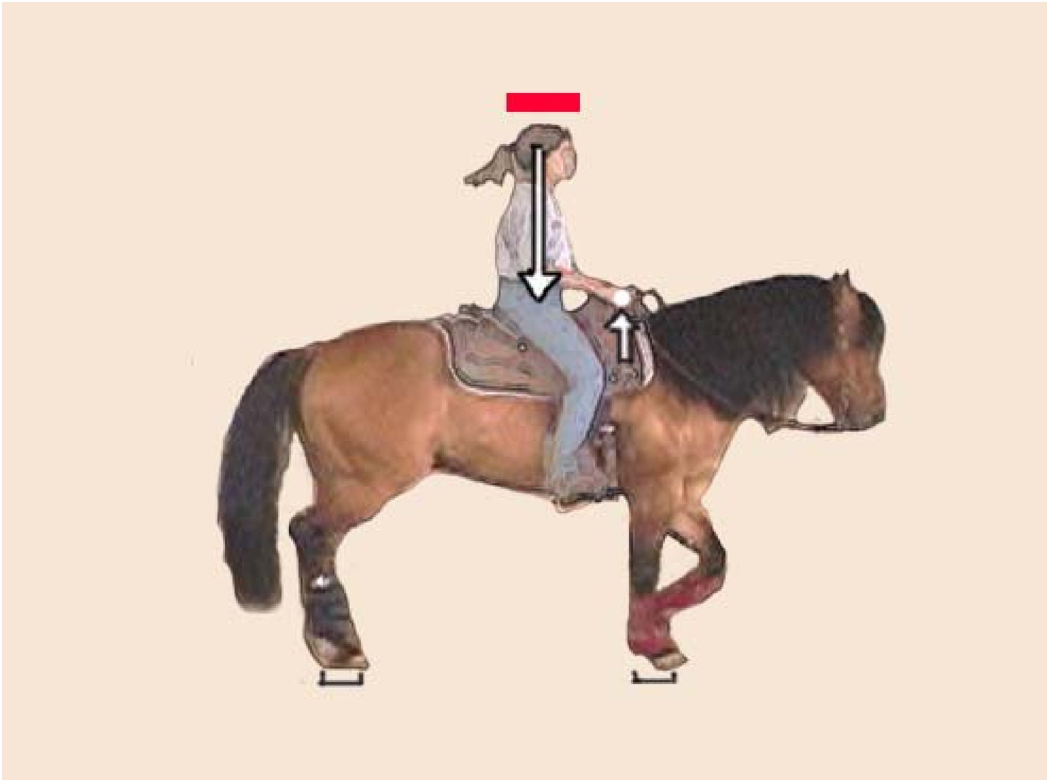

Fig. 6. The rider sinks back down.

This in and out movement of the front and rear legs creates the noticeable bounce described by Susan Harris. The rider's body movement is mainly from the waist and hips straight up and down. The other noticeable detail, seen in Figures 5 and 6, is the secondary movement of the rider's ponytail and the rider's hands. As the rider and horse fall down in the movement the ponytail and hands rise in the air. When the rider bounces up the ponytail falls back down hitting the back of the rider's head and the hands move slightly down.

5.3 Gallop

The gallop, shown in Figure 7, has the following features: high speed, one airborne phase per stride, a four-time beat, and non-lead and lead hindlegs and forelegs. The gallop consists of a series of springs through the air during which the horse never has more than two feet on the ground at once and usually only one.

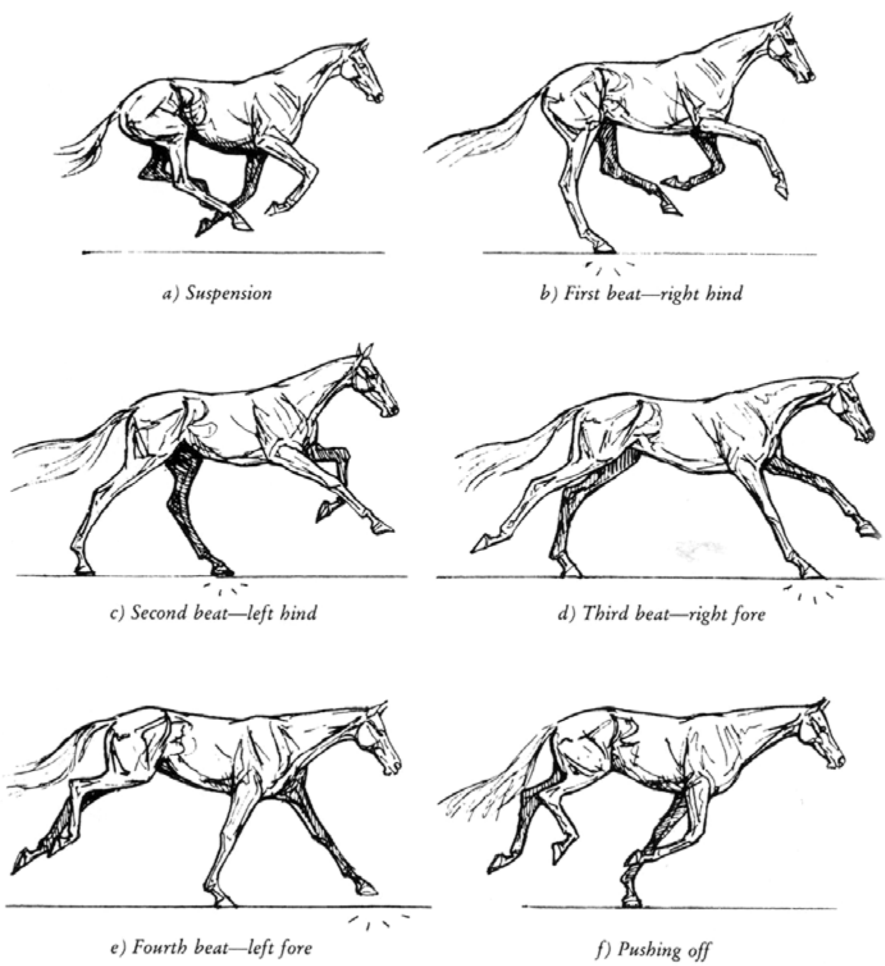

Fig. 7. The gallop in motion [Harris 1993].

The gallop uses dynamic equilibrium. According to Dr. Hillary Clayton, “this means that balance is maintained through the virtue of having forward motion. In spite of having only three, two, one or no feet on the ground, the horse maintains his balance because as his body falls toward the position of the center of gravity, another limb is placed on the ground which 'catches' the horse’s weight, supports the body and projects it forward.” [Clayton 1998] The faster the horse’s hind feet are driven against the ground the more the horse will depend on dynamic equilibrium to stay upright [Pilliner et al. 2002].

Fig. 8. Tana Rawson’s gallop sequence.

The gallop sequence shown in Figure 8 was performed by Tana Rawson. Compared to the trot the gallop has much more airtime and one complete cycle of motion is much longer. The rider leans back as the horse's hind legs thrust its body into the air and leans forward as the hind legs start to land. The rider makes this change from leaning slightly back to forward when the horse is in mid air. The rider's arms are brought slightly into her body as she rises in the air and slightly out from her body as she and the horse fall back to the ground from the airborne phase. Her ponytail lifts up as she rises into the air, stays up while in the air, and falls after the horse's rear legs hit the ground.

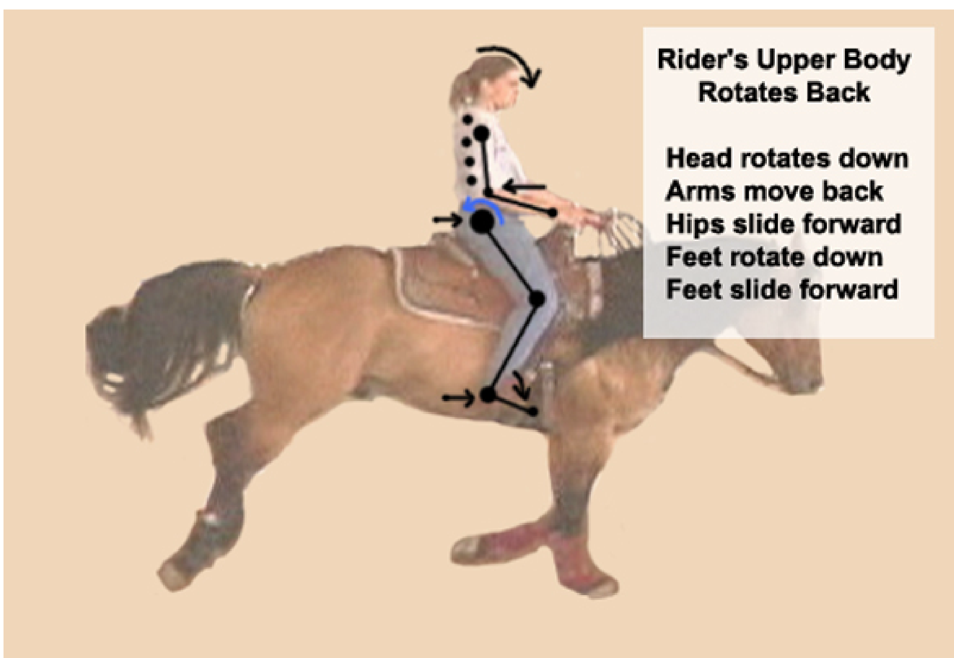

Fig. 9. Rider's rotation backward in the gallop.

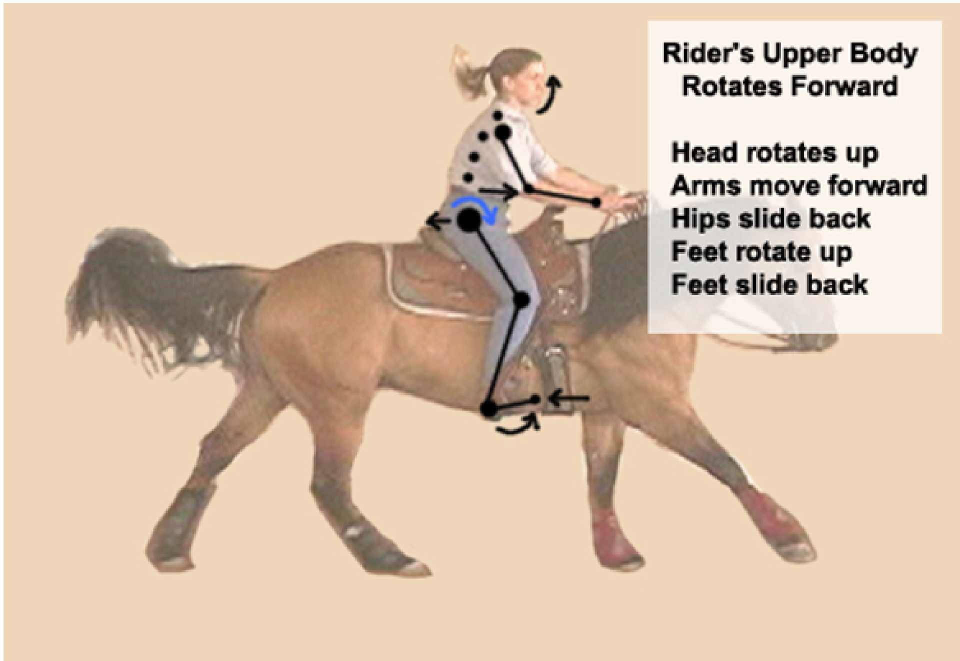

Fig. 10. Rider's rotation forward in the gallop.

As the rider rotates slightly back and forward in the gallop cycle, the rider's head, arms, hips and feet move along with the rotation. When the rider's upper body rotates back, as in figure 9, her head rotates slightly down, arms move back, hips slide forward, feet rotate down, and feet slide forward. When the rider's upper body rotates forward, as in figure 10, her head rotates slightly up, arms move forward, hips slide back, feet rotate up, and feet slide back.

5.4 Rear

The upward movement of the rear is similar to that in the take off of the jump. The hind legs have to support the horse as the forelegs rise up from the ground and the horse's center of gravity is shifted back. Rearing is usually a response to a threat signaling that the horse does not want to go on and by the increase of height the horse makes himself more fearsome. When rearing up the hind legs can support all of the horse's weight, but in order for the horse to stay up in the air longer it will often use a kicking motion to aid balance. The horse's head also leans back to help shift more weight over the hind legs.

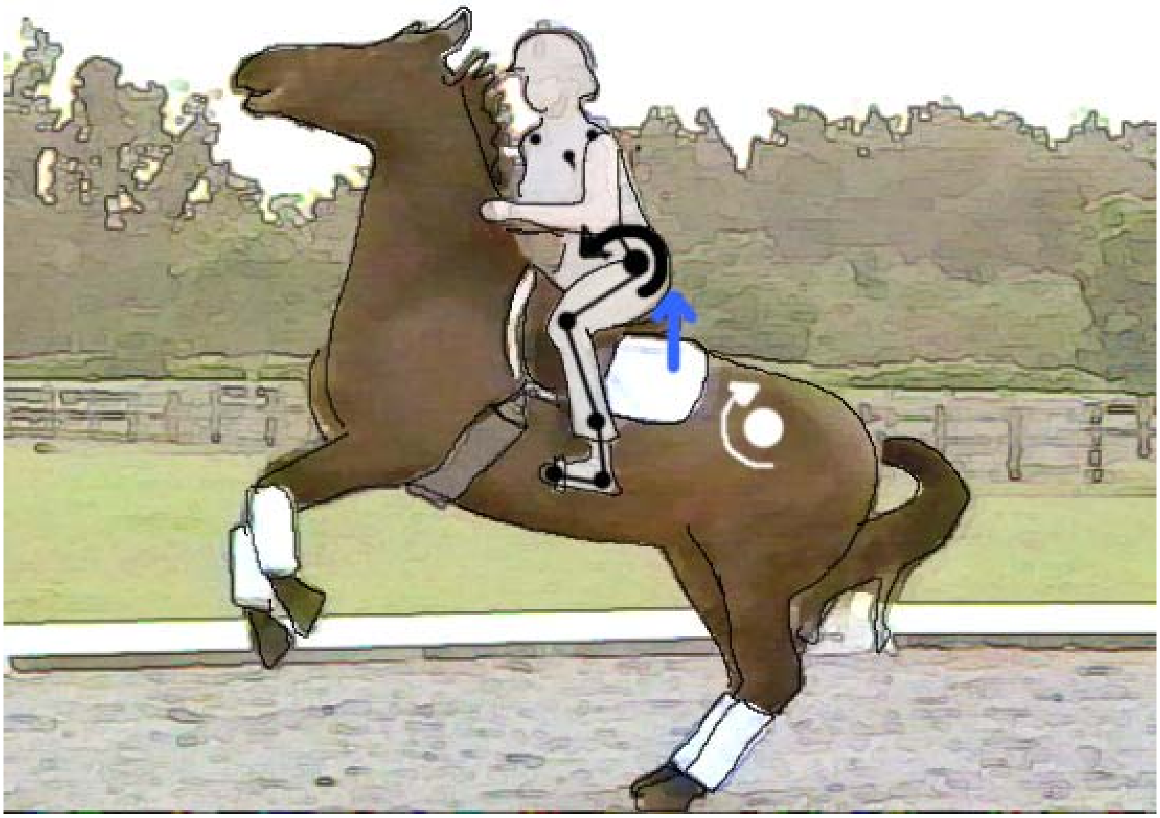

Fig. 11. Rider's movement when the horse rears.

Figure 11 shows how the rider leaned forward closer to the horse's neck, raising her seat from the saddle and shifting her feet slightly backward. As the rider leaned forward her hips translated forward and her lower back and hips rotated forward.

5.5 Stop

In the act of slowing to a stop from a gallop the horse's center of gravity shifts backward. The horse brings his hind hooves and hocks under itself in a locked position. The horse bends his back, bringing its rear legs and hocks up further under his body while maintaining forward motion and slides on his rear hooves. The front limbs provide more braking, which is used in combination with the carrying force of the front limbs to push the shoulders and forehand upwards and backwards.

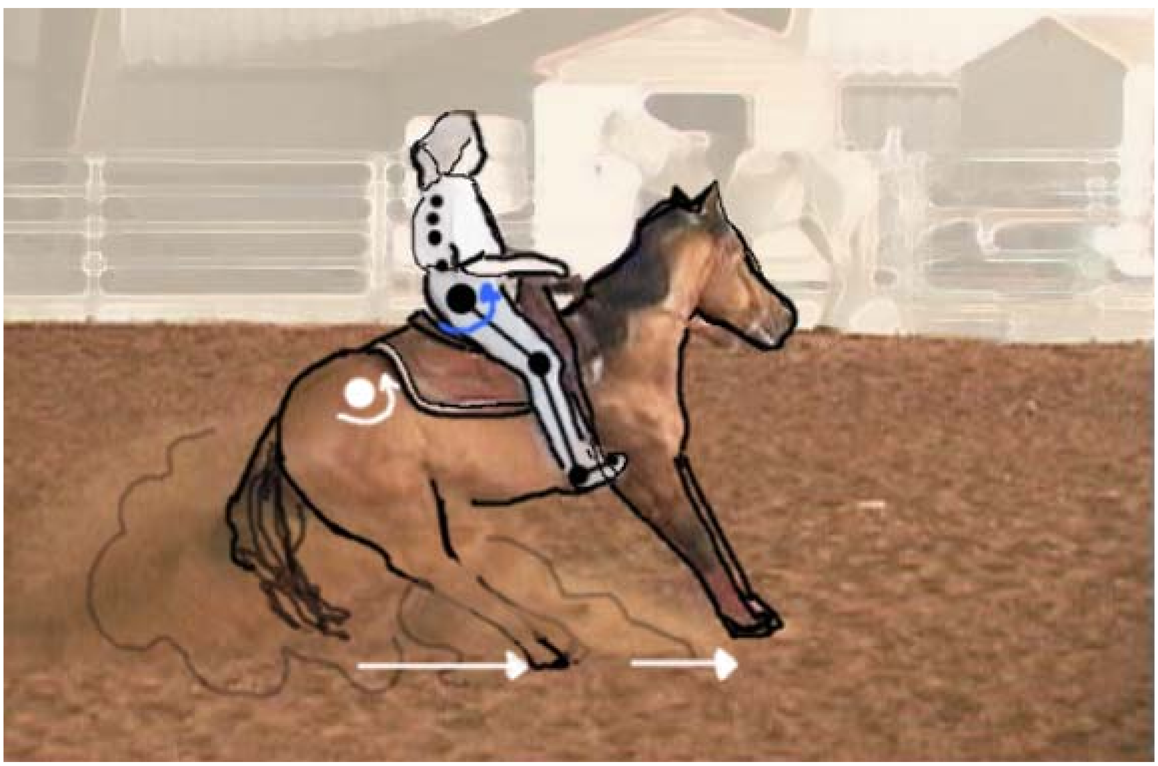

Fig. 12. Rider's movement as the horse stops.

In figure 12 we see that, as the horses hind legs engage under the horse's body and the forelegs straighten out in front of the horse for more breaking, the rider leans back to compensate for the backward shift in center of gravity. The rider's feet shift forward similar to the horses in a breaking movement and her arms shift back with the backward rotation of her upper body.

5.6 Bucking

William Thayer, in his book *Marvels of the New West*, quotes a stockman who gives a colorful description of a bucking horse: " When a horse bucks he puts his head down between his legs, arches his back like an angry cat, and springs into the air with all his legs at once, coming down again with a frightful jar, and he sometimes keeps on repeating the performance until he is completely worn out with the excursion. The rider is apt to feel rather worn out too by that time, if he has kept his seat, which is not a very easy matter, especially if the horse is a real scientific bucker, and puts a kind of side action into every jump." [Thayer 1890]

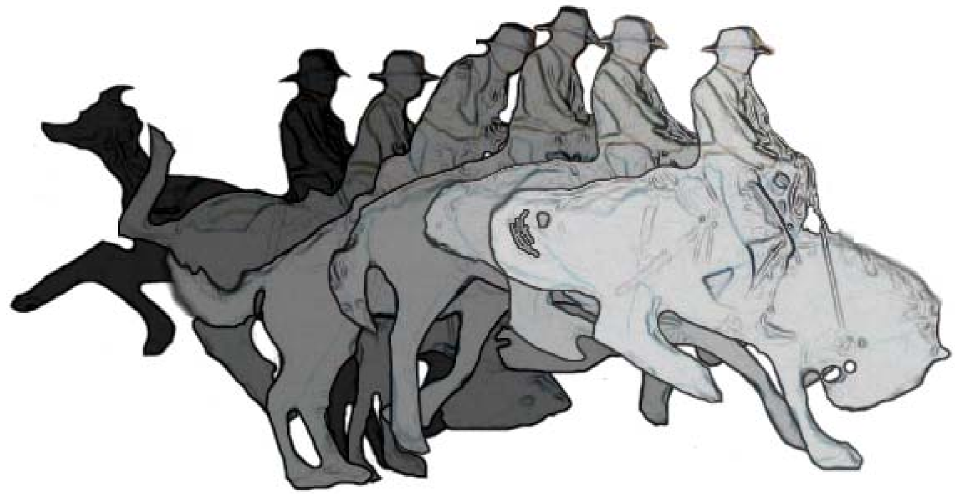

Fig. 13. Bronco riding motion.

With the bronco movement the rider's motion, depicted in figure 13, is very dynamic. As the horse lifts his forelegs and rotates its back upwards, the rider leans forward. As the horse lifts his rear legs and rotates its back downwards the rider leans backwards. There is some side-to-side motion of the rider as the horse twists its body and arches it back.

6. GENERAL MECHANISMS

The detailed movement of a horse and rider will be characteristic of the individuals. Weight, muscle development, size, and training of the horse and rider will effect how they move together, but before one can start thinking about all of these factors a general set of principals needs to be determined. These principles need to establish some relations between the horse and rider that can help simulate the movement. The following analyzes what parts of the horse cause a rider to move as they do.

6.1 Horse's Foot Support

There are several gaits that a horse performs. These can be analyzed by different footfall patterns like the two beat trot, three-beat canter, or four-beat gallop and walk. Rather than writing a different expression for each of these gaits it would be helpful to analyze the height of the hooves and their position in relation to the horse at each point in time. According to Susan Harris, "Movement in any stride (trot, canter, etc.) is accomplished stride by stride. A stride is a complete cycle of movement in which all four legs complete their motion and move the whole horse. A step is a movement of one leg. Each leg goes through four phases during a stride: swing, impact, support and thrust." [Harris 1993]

Since the legs are the support system for the horse, analyzing the stages the legs are in, according to their position in space, is very important to this research. Much of the rider's movement is about balance and stability. The rider is trying to stay on the horse and make the ride as easy and comfortable as possible for himself and the horse. The horse is trying to stabilize himself and the rider to be able to move with ease.

One factor that might influence a horse's stability is the number of feet the horse has on the ground. A horse will do very well with only one or two feet on the ground during a gallop, but as the speed is reduced like in a walk, there is an increase in the number of supporting feet [Clayton 1998]. The periods of support by the feet also become longer. This was taken into consideration in the development of the expressions by evaluating the height of the feet off the ground. The greater the total height of all the horse's feet the more dynamic the rider's motion would be and the more the rider has to compensate to stay balanced.

Besides just the height of the horse's feet, the calculations depend on what set of feet are lifted off the ground, the front set or the back set. Generally, when the front set of feet are lifted the rider leans forward and if the back set is lifted the rider will lean backwards. Plus, In a standing horse the front limbs carry about 55% to 60 % of the horse's weight, the hind limbs about 40% to 45% [Harris 1993]. So the front limbs will have more influence over a calculation than horse's back limbs.

6.2 Horse's Height and Rear Rotation

As a set of horse's legs lift in the air for a jump the horse's body also rotates up or down. This is usually done when the horse is in dynamic equilibrium, which according to Dr. Hillary Clayton, " means that balance is maintained through virtue of having forward motion. In spite of having only three, two, one or no feet on the ground, the horse maintains his balance because as his body falls toward the position of the center of gravity, another limb is placed on the ground which 'catches' the horse's weight, supports the body and projects it forward. This is repeated for each limb placement. The faster the horse is moving, the more he relies on dynamic equilibrium, and the less need he has for static equilibrium. Conversely, the slower the forward progression, the more the horse needs a large base of support to compensate for the loss of dynamic equilibrium, and this is achieved by having more feet in contact with the ground." [Clayton 1998]

For the simulation of the rider the height of the horse and rotation of the horses rear pivot helped simulate this dynamic equilibrium. In movements where the horse has much forward progression like the jump, there is greater rotation in the horse's body upward and the horse's feet rise up creating more dynamic movement in the rider.

6.3 Horse's Foot Position Forward or Backward

Another important attribute to analyze is the position of the horse's limbs forward or backward. According to Susan Harris, "If a horse wants to stop suddenly, all four limbs are fixed in a forward position like struts. The opposite occurs when the horse is trying to maximize propulsion, as in accelerating from a standing start, all four limbs tend to act behind the vertical position." [Harris 1993] When there is little or no propulsion forward like in the case of the trot the average position of the horses limbs are directly under the horse. In cases like this the rider doesn't have to lean forward or backward shifting his or her center of gravity because the horse's legs are well positioned under him. The rider will only bounce up and down.

In summary the expressions to simulate the rider depend on the height of the horses feet, which set of feet are lifted, the front or back, and then if those sets were forward or backward in relation to the vertical position of the horse. The expressions also consider the height of the horse off the ground if his back is arched. The last variable is how much the body of the horse is rotated from the horse's rear rotational pivot.

The key to generating the rider's movement was finding out in what proportions did a combination of these elements effect the rider's movement. Then, constraints needed to be put on the movement of the rider so that he wouldn't lean too far forward, his head wouldn't rotate through his chest, or his legs would not intersect the horse.

7. CHARACTER SETUP

Two rigs where set up using character setups from industry experts. Since the rigs were setup with the advice of these professionals the rigs are a good representation of a character rig one would generally use for a human and horse. Figures 14, 15, and 16 represent what these character rigs looks like in the Alias|Wavefront's software program Maya.

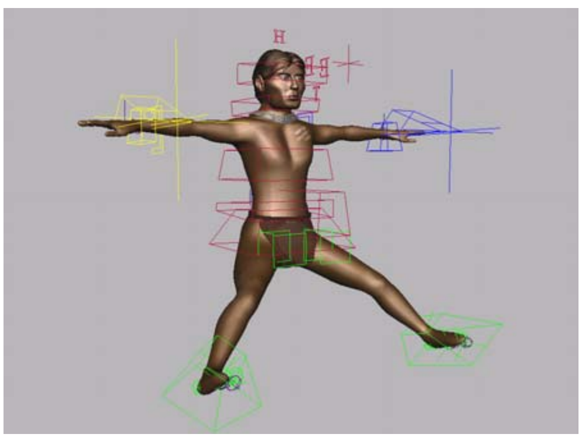

Fig. 14. Rider rig.

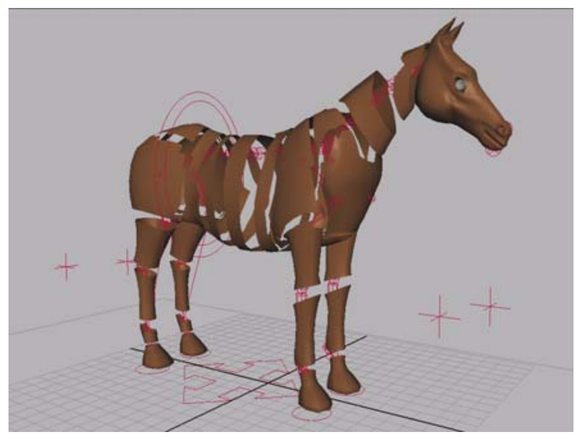

Fig. 15. Horse rig.

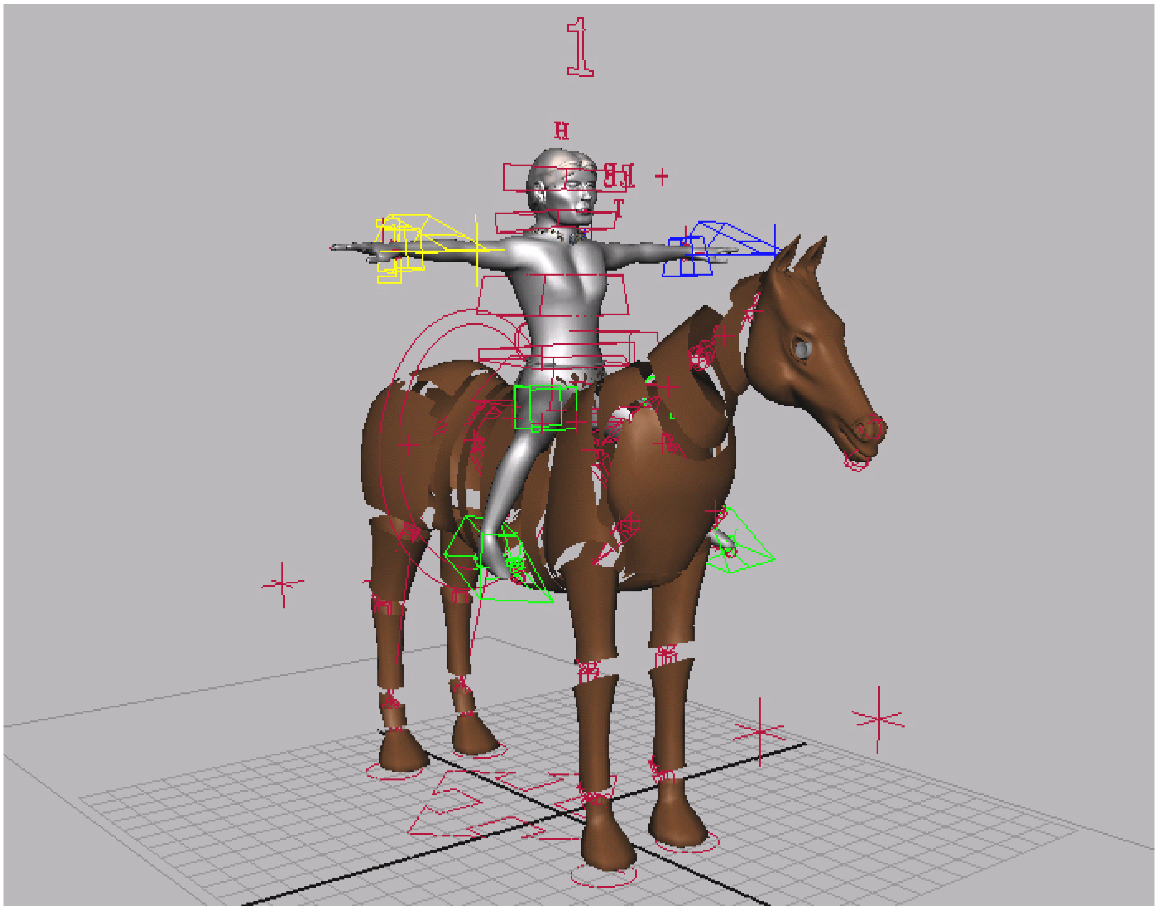

Fig. 16. Combined horse and rider rig.

When analyzing the horse character rig one can see there are several controls that are easy to monitor. Based on their movements they can be used to tell other controls in the rider's body what to do. Figure 17 highlights the areas of the horse's rig that are evaluated.

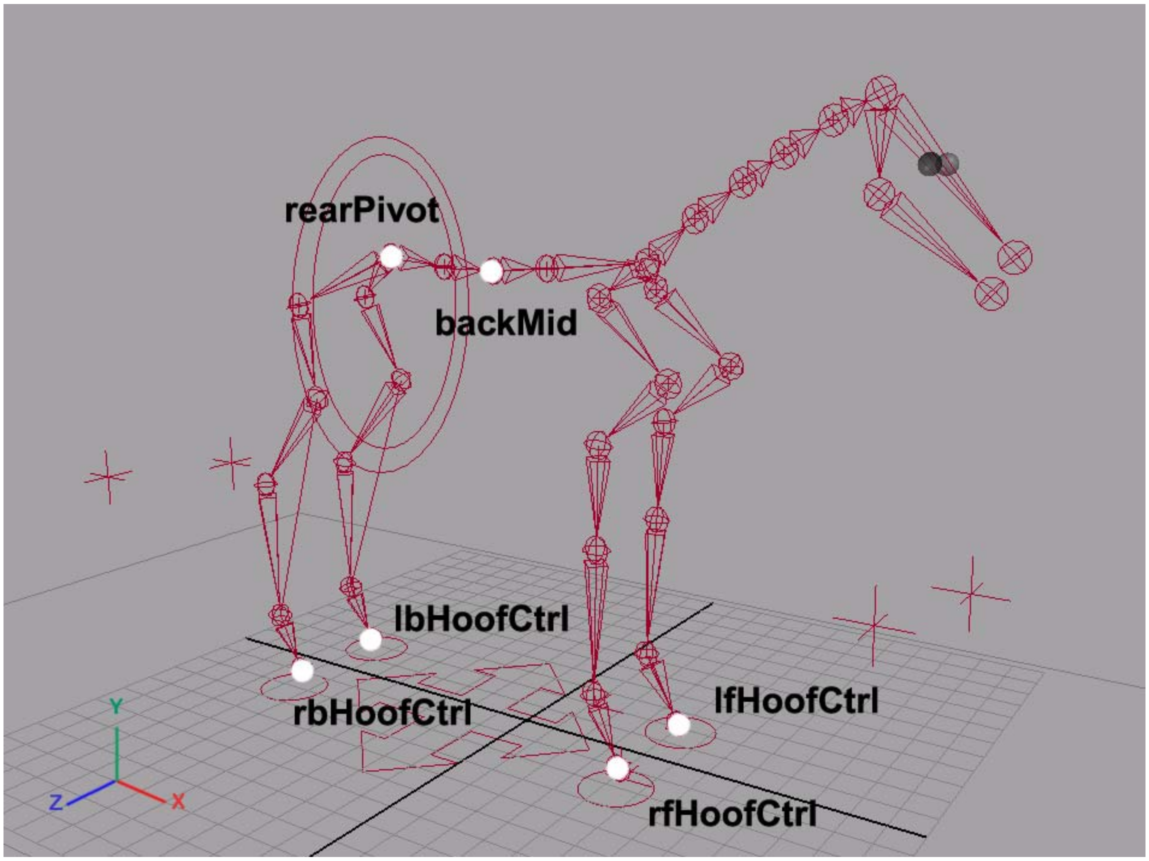

Fig. 17. Joints that drive the rider’s animation.

These areas consist of the hooves, rear rotational pivot, and the horse's mid back pivot. These controls are commonly used in a quadruped rig, which will ease in the applicability of the expressions to other quadruped rigs.

In each of these rigs there are many joints that interact with each other. To help in calculations and to keep track of how these joints move one has to be consistent with a set of principals for axis rotation. For these character rigs the joint orientations were set up as follows:

Rotate Z = bend front/back	Translate Z = side to side
Rotate X = twist	Translate X = forward and backward
Rotate Y = side to side	Translate Y = up and down

The rotations were set according to the usual orientations used in the industry to allow further ease in transferring the scripts. The expressions are based on joint rotations such as: riders_joint.rotateY = horse_joint.rotateY x -1;

If this basis for the joint rotation setup is kept one knows that if a script is going to be applied to the twist movement of the character's wrist, the rotation about the X- axis will need to be targeted. If a script needs to alter the rider's translation from front to back the X-axis of the translation needs to be targeted.

8. APPLIED CALCULATIONS

The expressions used to automate the movement of the rider are basically mathematical equations that relate the horse's movement to the rider's movement. By evaluating the hooves, rear rotational pivot, and the horse's mid-back pivot the rider's movement is generated.

8.1 Rider's Lower Back and Waist

One of the most important parts to generating the rider's movement was finding what needed to be analyzed to generate the rider's lower back rotation as in Equation 1. Once the lower back rotation was found the rest of the rider's body movements could be generated. The equation below shows what was analyzed on the horse to generate the lower back rotation forward and back for the rider.

Equation 1:

Rider's lower back rotation forward and backward =

[(Horse's rear pivot forward and back) x (horse's height from the ground + h_1) x w_1]

+ [(Average position of the horse's front feet forward or back) x w_2]

+ [(Average position of the horse's back feet forward or back) x w_3]

+ [((Height of horse's front feet)

x ((abs(Horse's rear pivot rotation forward and backward) + h_2) x w_4) x w_5)

– ((Height of horse's back feet x w_6) x w_7)]

Through experimentation w_1 =0.07, w_2=0.25, w_3 = 0.25, w_4 = 0.1, w_5 = 0.9, w_6 = 0.4, w_7 = 0.40 were used to give more influence to different parts of the equation. These weights are important to create the correct rider motion. The values h_1 = 2, h_2 = 5 were used to start the joint positions at a value greater than zero.

As shown in the calculation for the rider's lower back rotation several factors were considered. The first is the height of the horse off of the ground. The greater the height of the horse off the ground the greater influence the horse's rear rotation pivot had in the calculation. The second is the average position of the horse's front and back feet translated forward or backward shown in Figure 18.

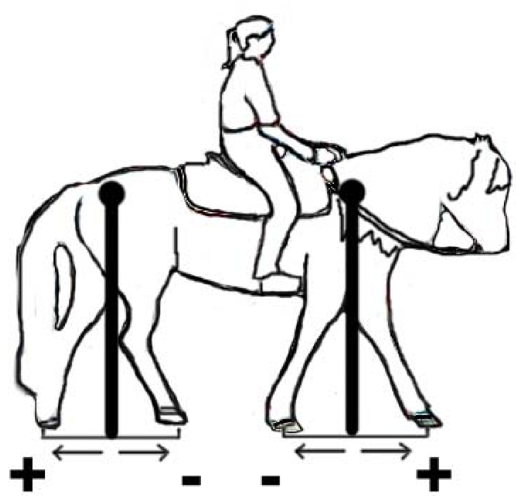

Fig. 18. Position of the horse's feet.

If both sets of legs move towards the center of the horse as in Figure 19, the rider will lean back. If both sets of move out, as in Figure 20 the rider will lean forward.

Fig. 19. Rider in backward position as both sets of hooves are in the negative direction.

Fig. 20. Rider in forward position as both sets of hooves are in the positive direction.

The sets of legs also counteract each other so that if the front legs average position is forward, but the back legs average is more forward the rider will lean slightly back rather than forward.

The third contributing factor to the rider's lower back rotation is the height of each set of the horse's feet and rotation of the rear pivot joint. In the Figure 21 and 22, the rider would be leaning back if just the position of the feet were analyzed forward or backward. In a case like the jump there is much more rotation in the rear pivot. As there is more rotation in the rear pivot the greater the influence the height of the horse's front feet have in the rider's rotation. The absolute value of the rotation of the rear pivot is taken since in the following cases the rider needs to lean forward when the horse rotates both up and down. The height of the feet determines how much the rider leans forward. When the horse's front feet are on the ground and there is rotation in the rear pivot, the rider will lean in a slightly backward position instead of forward, but as the horse's front feet rise from the ground the rider will lean increasingly forward.

Fig. 21. Rider leans forward as the horse's back pivot rotates up.

Fig. 22. Rider leans forward as the horse's back pivot rotates down.

The rider's lower back in Equation 2 also rotates side to side the same amount of the horse's hip rotation, but in the opposite direction. Figure 23 displays this movement of the rider in the opposite direction that the horse leans.

Equation 2:

Rider's lower back rotation side to side = Horse's rear pivot rotation side to side x -1

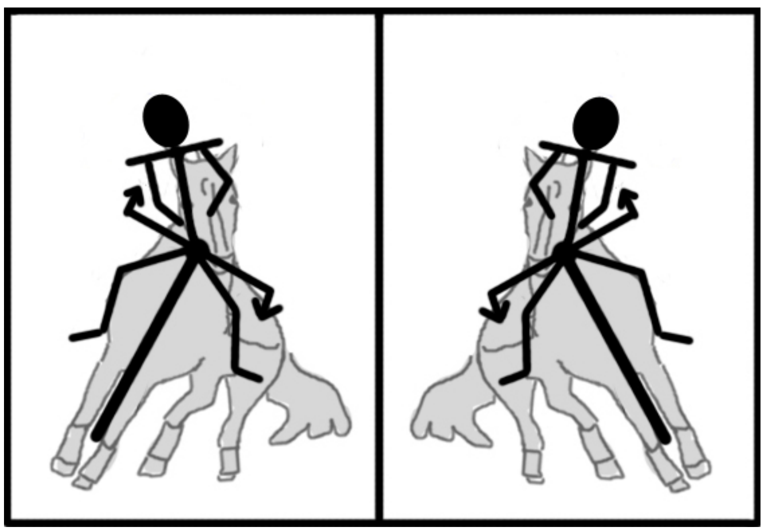

Fig. 23. The rider's side to side movement.

The rider will also slightly twist its back toward the direction the rider is leaning side to side. In Equation 3, a weight of w_1= 0.5 is multiplied by the rider's lower back rotation to decrease the amount the rider's lower back will twist.

Equation 3:

Rider's lower back twists = Rider's lower back rotation side to side x w_1

The waist of the rider depends on the rider's lower back rotation calculated previously in Equation 1. In Equation 4, the waist will rotate slightly more than the rider's lower back rotation, with a weight of w_1= 1.7, to give the rider a nice curve in the spine. The other joints of the rider's back from the waist on up follow this rotation in the waist.

Equation 4:

Rider's waist rotation forward or backward =

Rider's lower back rotation forward or backward x w_1

8.2 Rider's Hips

The rider's hips rotate forward and backward with the rotation of the rider's lower back rotation. Through experimentation w_1= 0.8 is a good value to use to limit how much influence the rider's lower back rotation has in the rider's hip rotation in Equation 5.

Equation 5:

Rider's hip rotation forward and backward = Rider's lower back rotation x .8

The hips of the rider rotate side to side with the same amount and direction of the horse's hip rotation shown in Figure 24. In Equation 6, a weight of w_1 = 0.5 limits the rider's hip rotation to be half of horse's hip rotation and a weight of w_2 = 2 increases the amount of influence the difference between the height of the horse's two rear feet have in the equation.

Equation 6:

Rider's hip rotation side-to-side = [horse's rear pivot side-to-side x w_1]

+ [(Right back horse hoof – Left back horse hoof) x w_2]

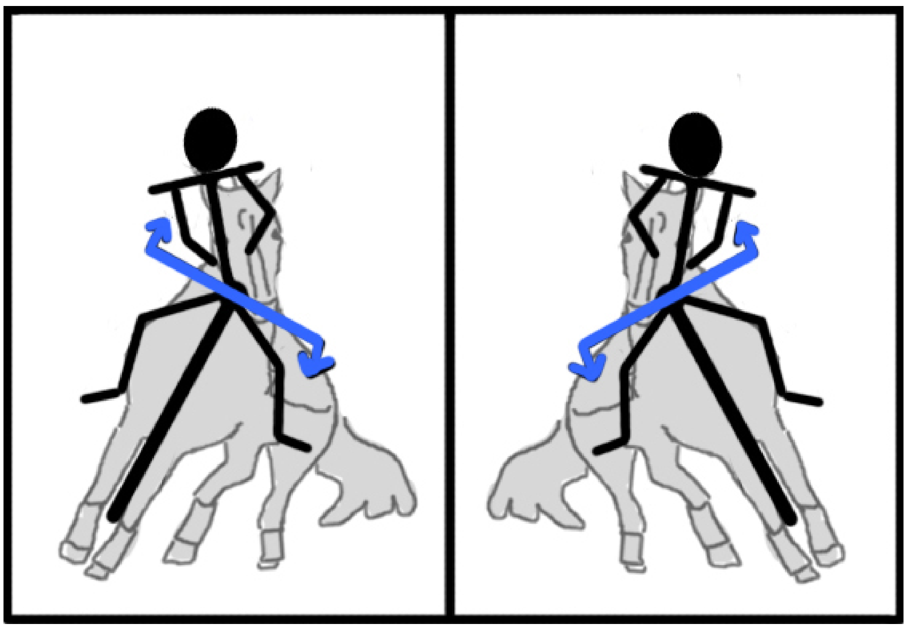

Fig. 24. The rider's hips rotate with the horse's hips.

The equation developed for the hips also takes into consideration if one of the back legs of the horse is raised higher than the other as in Figure 25. This way the rider can compensate for the shift in the horse's hips. According to Susan Harris, "The horse's back muscles work alternately as he strides with one hind leg and then the other. Each side of the back rounds and rises as the hind leg on that side is engaged and grounded, and it dips as the leg stretches out behind and then is carried forward through the air.

This alternating upward movement is easy to see if you watch the horse's hips moves away from you, and can easily be felt by the rider." [Harris 1993] In summary the rider's complete hip rotation side to side depends on half of the horse's rear pivot rotation side-to-side, plus the difference in height of the horse's back two feet.

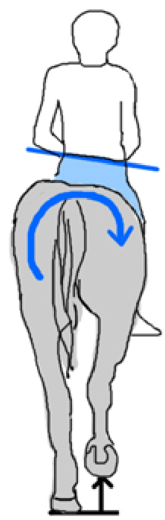

Fig. 25. The rider's hips rotate as one of the horse's rear legs lift.

8.3 Rider's Lift in the Seat

When one watches a horse and rider they will notice much bouncing up and down. The researcher has defined this bounce as the lift of the rider's seat. Figure 26 shows that in a trot this lift is very minimal and in the jump the lift is much more extreme. In Equation 7 several factors are evaluated to make this lift to work for all cases.

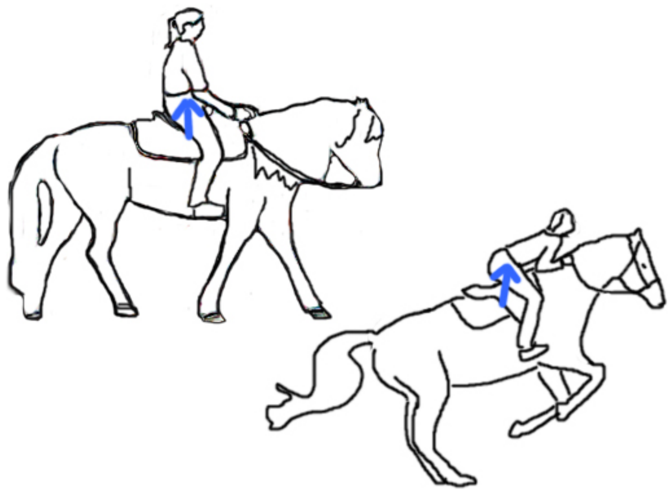

Fig. 26. The lift of the rider in two different cases.

Equation 7:

Rider's lift or translation up or down=

[(Distance between horse's front feet) + (Distance between horse's back feet)

+ (Horse's front feet location forward or backward)

+ (Horse's back feet location forward or backward)

+ (Height of horse's front two feet x w_1)] x w_2

A weight of $w_1 = 2$ was given to increase the influence of the horse's front feet in the lift. The complete equation was multiplied by $w_2 = 0.01$ to be able to take into consideration many different variables but limit their sum to be a small amount of distance for the rider to lift.

The first variable introduced in the equation is the distance between each set of the horse's feet as in Figure 27. For the trot, when the distance between the front two feet is the greatest and the back two feet is the greatest the rider lifts out of the saddle.

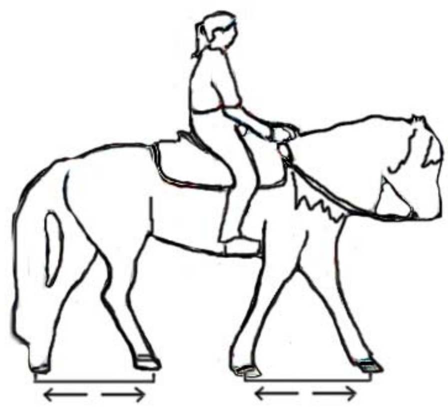

Fig. 27. In the trot the rider lifts when the difference between both sets of the horse's legs is the greatest.

In other cases like the jump the lift also takes into consideration the average position of the horse's legs forward or backward in relation to two positions on the horse. When the horse's back set of feet move towards the center of the horse a positive value is added to the rider's lift and when they move back a negative value is added to the equation, as in Figure 28. This will help simulate the rider's lift in a case like the gallop where the rider's lift is the most when both sets of the horse's feet move towards the center of the horse.

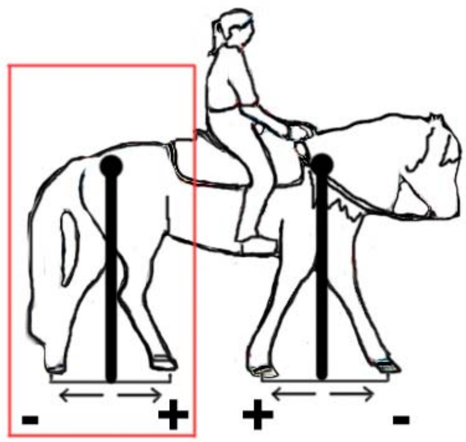

Fig. 28. Analyzing the horse's rear foot position.

In Figure 29 the same idea applies to the position of the horse's front feet. The foot position is measured according to the vertical position of the horse's shoulder blade. As the foot moves back from that position a positive value is added to the rider's lift and as the foot moves forward a negative value is added.

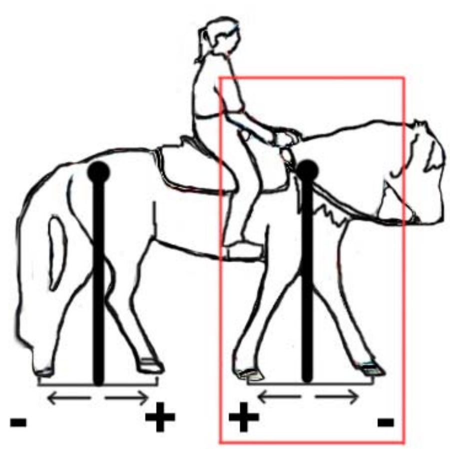

Fig. 29. Analyzing the horse's front foot position.

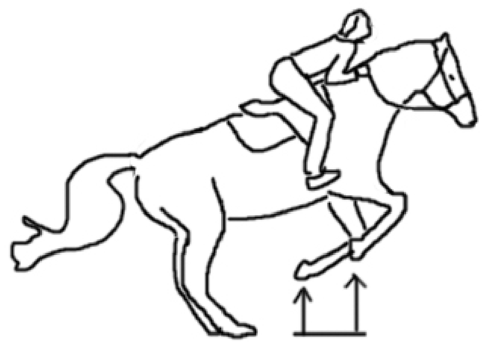

Fig. 30. The height of the horse's fore feet.

The final factor of the rider's lift is the height of the horse's front feet as in Figure 30. This helps add to the rider's lift in the case like a jump when the lift of the horse's front feet is much greater than in a less dynamic movement like the walk or trot where the horse's feet do not lift very height off of the ground.

8.4 Rider's Shift in Seat

When watching a horse and rider one will also notice that the rider's seat shifts forward and backward in the saddle. Much of this is due to the natural movement when you bend forward or backward, but some is also from rotation of the horse's body. Equation 8 shows how the shift in the rider's seat can be derived.

Equation 8:

Rider's seat translation forward and backward = [(Horse's rear pivot rotated up or down x w_1) – (Rider's lower back rotation forward or backward)] x w_2

Through experimentation $w_1 = 2$ was successful in increasing the influence of the horse's rear pivot rotation in the equation. As a horse rotates up the rider will shift its seat towards the front of the. A weight of $w_2 = 0.1$ was multiplied to the complete equation to scale down the translation of the rider's seat forwards and backwards. Figure 31 illustrates shift in the rider's seat backward when there is little or no rotation in the horse's rear pivot and the rider leans forward.

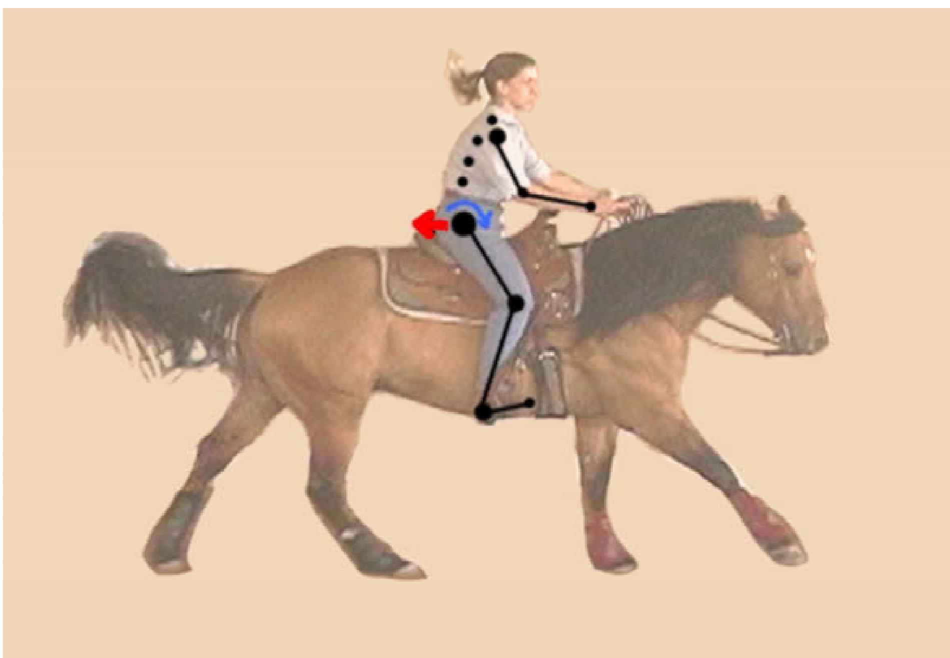

Fig. 31. Rider's seat shifts backward.

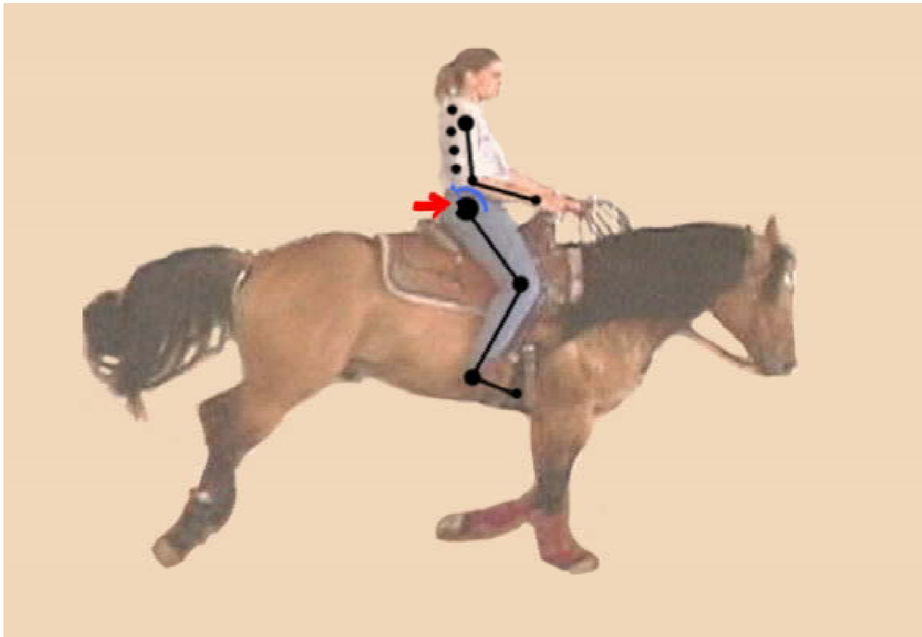

Fig. 32. Rider's seat shifts forward.

The rider shifts forward when there is little or no rotation in the horse's rear pivot and the rider leans backward, as in Figure 32. The shift of the rider was constrained to a minimal amount so that the rider would only slide within the range of a saddle.

8.5 Squash and Stretch

To increase the bounce of the rider, a little squash and stretch was added to the rider's head, neck, shoulders, and spine. Each joint was translated up or down according to a fraction of the distance the rider lifts out of the saddle, as in Equation 7. To start the rider off a little more squashed than the default rig position the researcher used h_1= 0.1 to redefine the initial joint positions.

Equation 9:

Selected spine joint translates up and down = [Joint's initial position - h_1]

+ [Lift of the rider up or down / w_1]

Equation 9 demonstrates how a fraction of the rider's lift could be used to calculate the rider's squash and stretch as in Figure 33. Through experimentation, $w_1 = 6$ was a good value to generate the squash and stretch. If a larger value is used the squash and stretch would be less and if a smaller value is used the squash and stretch will increase.

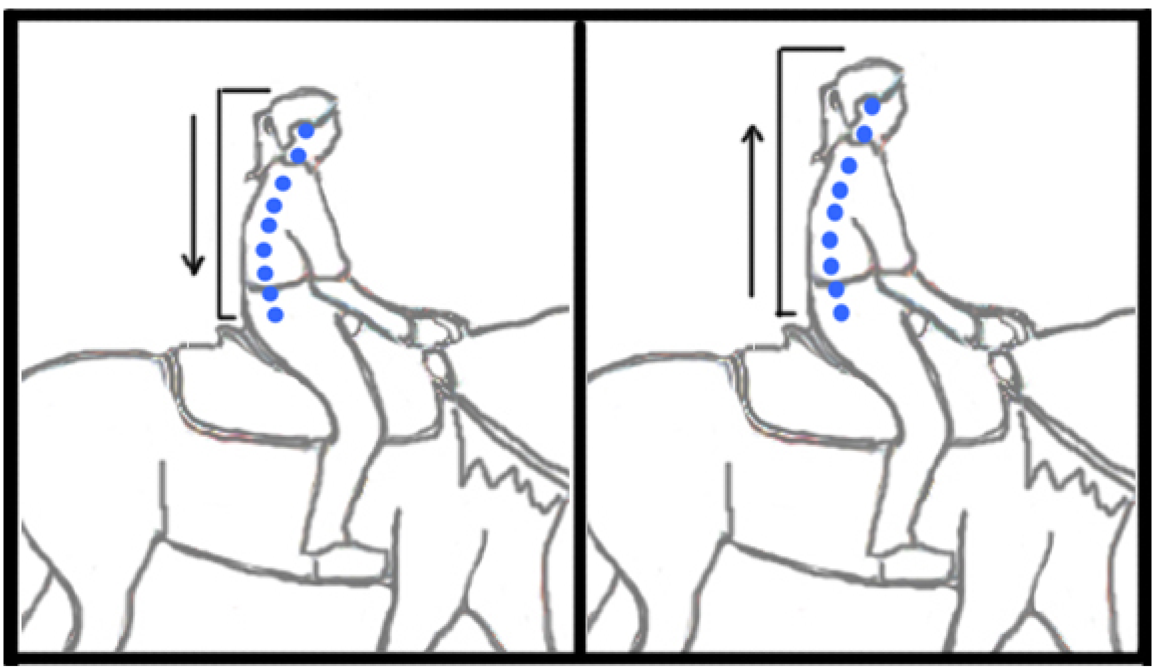

Fig. 33. Squash and Stretch.

8.6 Rider's Head

The head of the rider moves forward and back opposite of the lower back rotation so that the rider is always looking forward, not too far down or up as in Figure 34. In Equation 10, $w_1 = 0.9$ is a good weight to limit the value of the rider's lower back rotation. To scale the rider's lift up to increase rotation in the rider's head $w_2 = 18$ was applied.

Equation 10:

Rider's head rotation forward or backward = [Rider's lower back rotation x $-w_1$]

- [Rider's lift up or down x w_2] + [Rider's head rotated 5 degrees down].

Fig. 34. Rider's head rotation during a gallop.

In the jump in Figure 35 one can see how the rider rotates her head up as she leans forward for the jump and rotates it back down as she lands consistently looking forward.

Fig. 35. Rider's head rotation during a jump.

To make the head bounce more for a movement like the trot the lift of the rider out of the saddle is subtracted from the rotation of the lower back control. This makes the head rotate backward and forward more as the rider bounces. Five degrees was added to the equation to start the head off in a slightly more forward position.

Besides front and back, the rider's head also moves side-to-side in the opposite direction of the rider's lower back rotation side to side and in same direction of the horse's rear pivot rotation side to side as in Figure 36. Equation 11 calculates this rotation by analyzing the horse's rear pivot rotation.

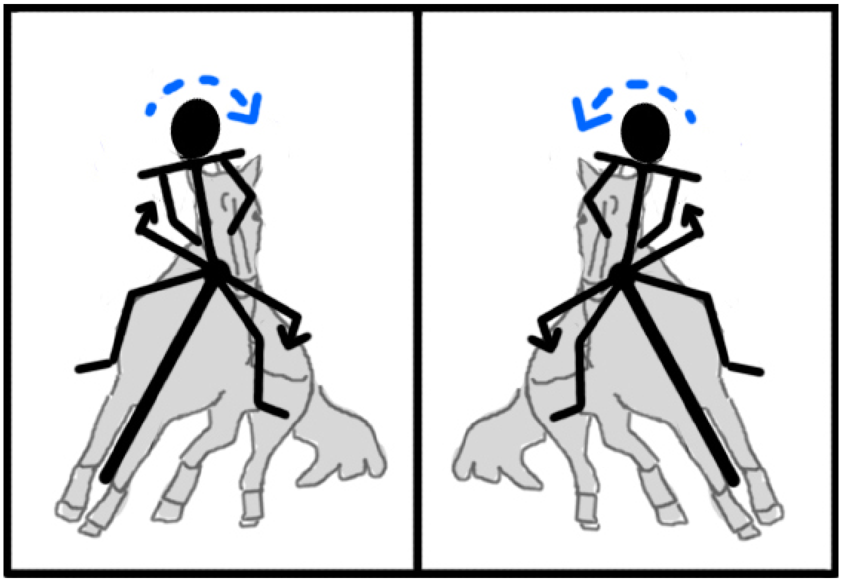

Fig. 36. Rider’s head rotation side-to-side.

Equation 11:

Rider’s head rotates side to side = Horse’s rear pivot rotation side to side x -1

8.7 Rider’s Wrists

The wrists move forward or backward according to the rider’s lower back rotation, when there is little rotation in the horse’s rear pivot. The more rotation there is in this pivot, the more the wrist motion depends on the horse’s front feet forward or backward.

Equation 12:

Rider’s wrist translated forward and backward = [Rider’s lower back rotation forward and backward x w_1] – [(Average position of horse’s front feet forward or backward) x (absolute value of the horse’s rear rotation up or down)]

The weight $w_1 = 0.0001$ gives less influence of the rider's lower back rotation to the rider's wrist translation than the average position of the horse's legs forward or backward, but when there is little or no rotation in the horse's rear rotational pivot, $a_1 = 0.0001$ will give just enough influence to translate the rider's wrists slightly forwards and backwards, as in Figure 37 and 38.

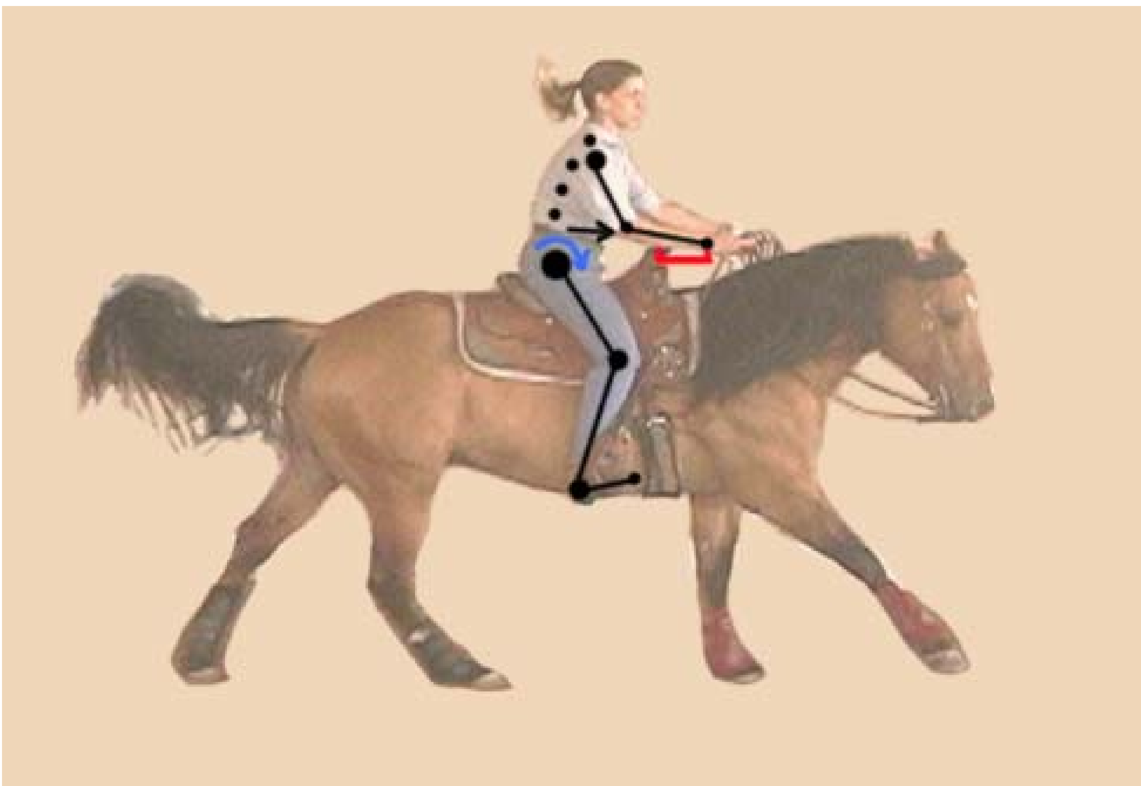

Fig. 37. Rider's wrists moving forward.

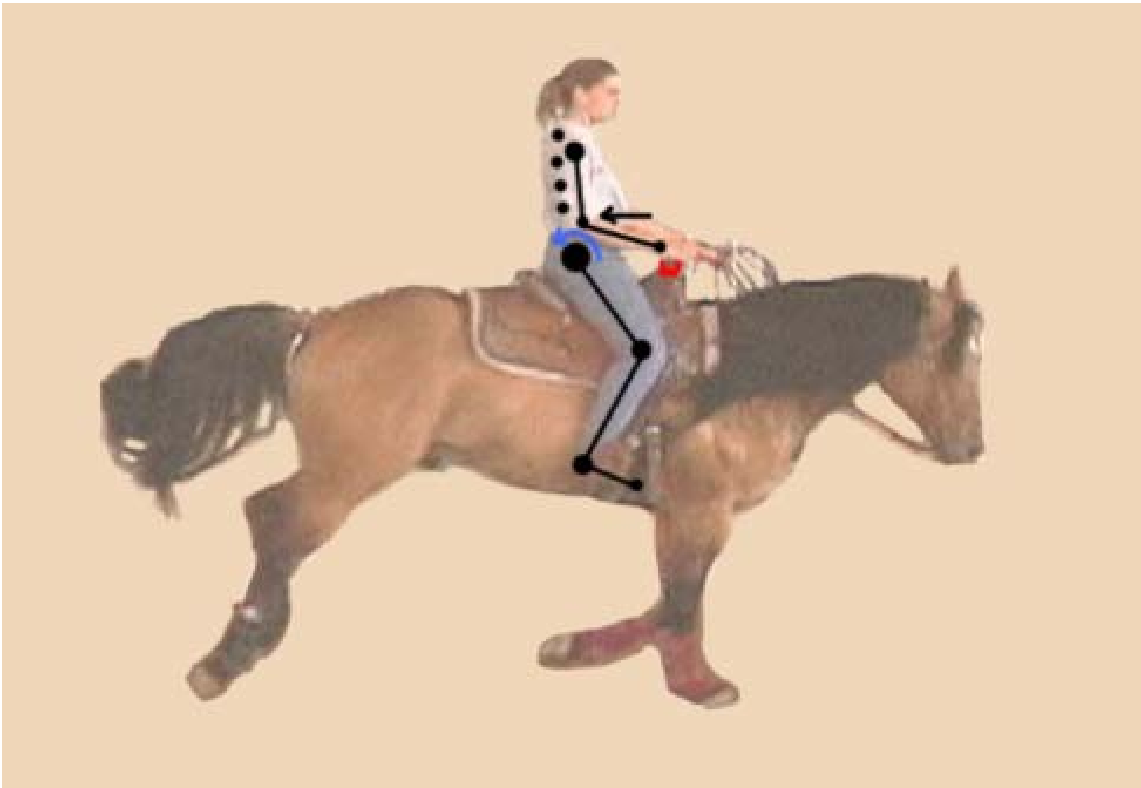

Fig. 38. Rider’s wrists moving forward.

The wrists move forward or backward according to the lower back, when there is little rotation in the horse’s rear pivot. The more rotation there is in the rear pivot the more the wrist motion depends on the horses feet forward or backward. The wrists also move up and down according to the height of the horse’s feet and the height of the horse in the air. Equation 13 calculates this movement.

Equation 13:

Rider’s wrist translation up and down = [(Sum of the height of all horse’s feet) x w_1]

– [(The height of the horse’s rear pivot) x w_2]

Through experimentation $w_1 = .03$ and $w_2 = .0005$ are good values to balance out the influence of the horse's foot height and the height of the horse's rear pivot. When there is no rotation of the horses rear pivot like in a trot the rider's hands will bounce up and down according to the height of the horse's feet. When the horse increases in height of the ground as in Figure 39 the height of the horse's rear pivot is subtracted from the equation so that the rider's hands do not lift too far in the air.

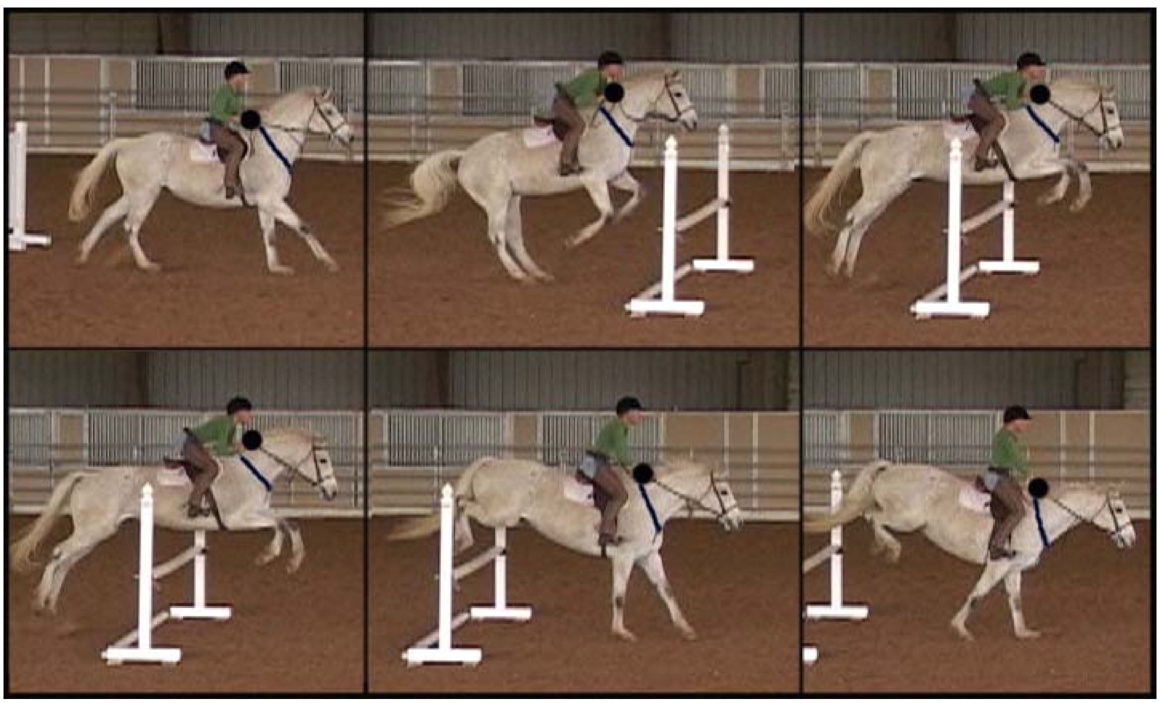

Fig. 39. Rider's hand movement in the jump.

8.8 Rider's Legs and Feet

The rider's foot positions with various movements were harder to analyze since they often blend in with the horse. The following calculations are based on what could be analyzed. In Equation 14 $w_1 = 0.005$ and $w_2 = 0.005$ limit the influence of horse's rear pivot rotation. A value of $h_1 = 0.8$ is added to the horse's rear pivot rotation so that in the case that the rotation is zero there will still be a small amount of movement in the rider's feet.

Equation 14:

The rider's foot translates forward or backward =

[(Average position of the horse's front legs forward or back)

x ((Absolute value of horse's rear pivot rotation forward and back x w_1) + h_1)]

– [Absolute value of the horse's rear pivot rotation forward and back

x rider's lower back rotation forward and back x w_2]

The rider's lower back rotation is multiplied by the horse's rear pivot rotation later in the Equation 14 to shift the rider's feet back as the rider would rise up for a jump and more forward as in landing from a jump. When there is little or no rotation in the horse's rear pivot the rider's feet translate forward and backward according to the position of the horse's front legs.

The rider's feet also rotate up and down. As they translate forward as in Equation 15 they rotate up and as they translate backward they rotate slightly down. This rotation is limited to in the expressions. A weight of $w_1 = 2$ increases the rotation of the rider's foot.

Equation 15:

Rider's foot rotation up and down = Rider's foot translation forward and backward x w_1

The feet of the rider move out and in colliding against the belly of the horse as the horse bounces up and down in the air. To simulate this effect the feet twist, rotate side-to-side, and the knees of the rider translate opposite the direction the feet translate out and in against the horse. For the rider's foot rotation in Equation 16 a weight of $w_1 = 1.7$ is given the height of the horse's feet. While this may seem like a large amount, the foot rotation is constrained to a certain degrees of freedom in the expressions.

Equation 16:

The rider's foot rotation side to side = [Sum of the height of all horse's feet] x $-w_1$

For Equation 17 the rider's feet move in and out from the belly of the horse when the horse's feet move up and down. Through experimentation $w_1 = 0.05$ and $w_2 = 0.05$ work well to balance the influence of the main variables in the equation.

Equation 17:

The rider's foot translates towards and away from the belly of the horse = [Sum of the height of all horse's feet x - 0.05] – [Rotation of the horse's rear pivot side-to-side x 0.05]

In Equation 18 a weight of $w_1 = 1.1$ limits the influence the rider's foot translation in the equation. The goal of this equation is to have the rider's legs swing out and in from the horse. By translating the rider's knees in the opposite direction of the rider's feet this swing is possible.

Equation 18:

The rider's knee translates towards and away from the belly of the horse = [Initial foot position] – [Rider's foot translation towards and away from the belly of the horse x w_1]

8.9 Rider's Cloth and Hair

Hair and cloth simulation is practically a whole other area of research so less time was spent on their calculations. The rider's hair and cloth were set up with joints that are driven by set driven keys in Maya. The researcher set up several attributes to control the rider's hair and cloth moving up and down and side-to-side. The rider's hair and cloth are simulated to go up and down as the sum of the height of all feet increases and decreases. The hair and cloth simulation works well less dynamic movements like the trot and not as well for more dynamic movements such as the jump.

9. RESULTS AND CONCLUSIONS

9.1 Jump

In the two movie files, jump_side.mov and jump_persp.mov, one can view the resulting animations for the jump. Figure 40 shows how the rider correctly leans forward in the jump as the horse rises for the jump. When the horse lands the rider straightens out his legs and leans slightly back. The rider's movement is very similar to the reference footage from the movie Monte Walsh. The main difference is the reference horse has slightly longer legs than the animated horse, which may cause a little variation between the reference and the animation, but the rider's animation overall is very comparable to the reference.

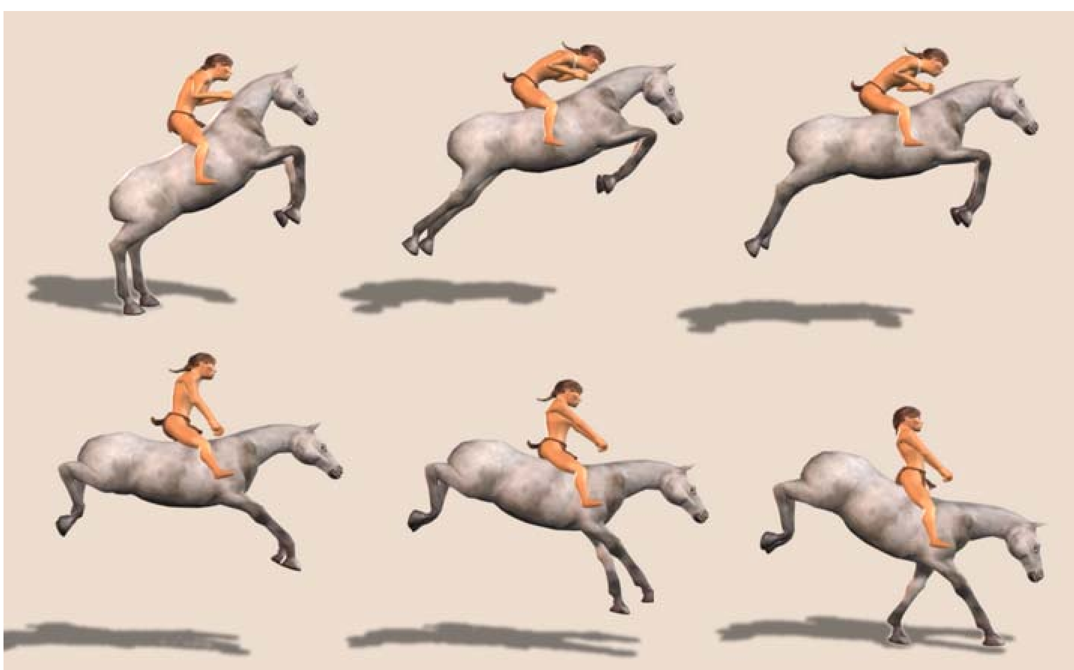

Fig. 40. The resulting rider animation for the jump.

9.2 Trot

In the three movie files, trot_side.mov, trot_persp.mov, and trot_layered.mov one can view the resulting animations for the trot. Since the trot movement of the horse and rider is less dynamic than the jump the still images in figure 41 will not illustrate this movement as well as watching the actual animation. To correctly simulate the rider's movement for the trot the rider needed to be able to bounce up and down as the horses legs moved in and out from each other. In the animation when the distance between each set of the horse's feet is the greatest the rider will bounce up and as they pass by each other the rider sinks back down. By being able to implement this in to the expressions that drive the rider's movement the resulting animation was successful. The bounce was exaggerated a little more than the referenced footage with some squash and stretch added to the rider's head, neck, and spine. Overall, the resulting animation of the trot was simulated successfully creating that signature bounce that one would see when watching a real horse and rider.

Fig. 41. The resulting rider animation for the trot.

9.3 Gallop

In the three movie files, stop_side.mov, stop_persp.mov, and stop_layered.mov, one can view the resulting animations for the gallop into a stop. In figure 42, one can see the rider's movement in the gallop. The rider leans slightly back when the average position of each set of the horse's limbs move towards the center of the horse. As the horse's limbs move out from the center of the horse the rider leans forward. As the rider leans forward and back his arms and feet move slightly forward and backwards as they do in the reference footage. The rider's seat also slides back as the rider leans forward and slides forward as the rider leans backward.

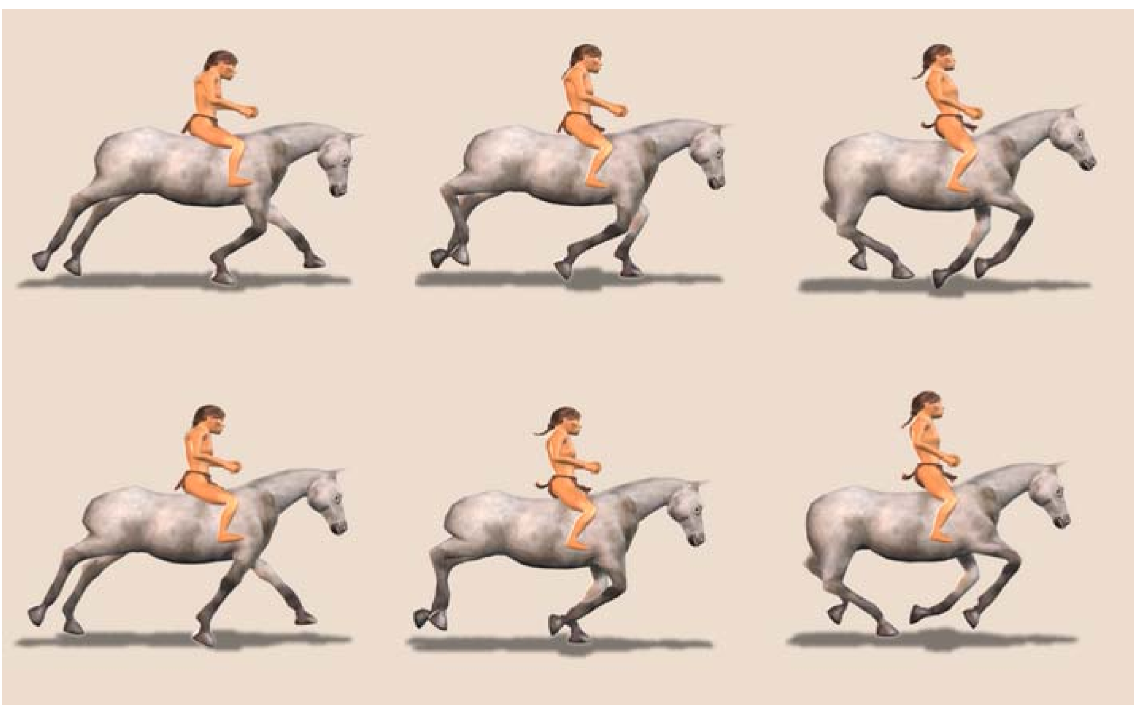

Fig. 42. The resulting rider animation for the gallop.

The lift of the rider is accurately simulated so that when all of the horse's limbs are towards the center of the horse and the horse's feet are off the ground the rider lifts into the air. The resulting motion of the rider for the gallop when compared to the reference could be loosened up to give the human rider an even more realistic quality, but the motion of the rider is very similar to the reference footage.

9.4 Stop

In the three movie files, stop_side.mov, stop_persp.mov, stop_layered.mov, one can view the resulting animation for the gallop into a stop. In figure 43, the sequence of images shows how the rider leans back and shifts his feet forward as the horse brings his legs under himself.

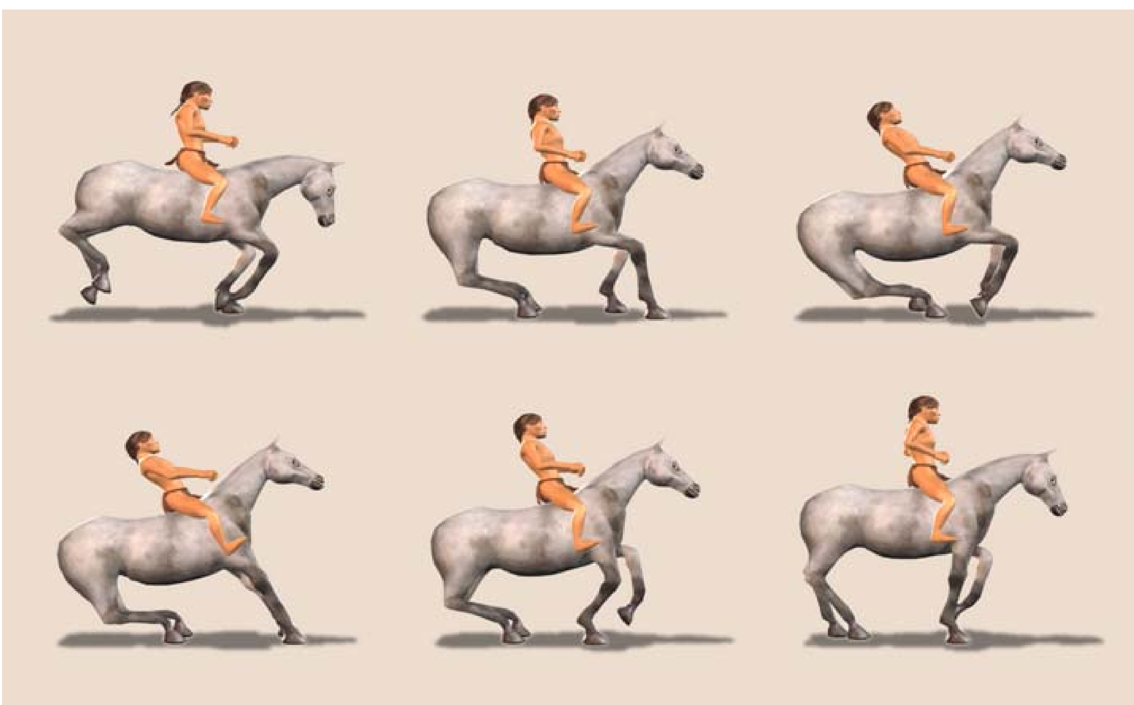

Fig. 43. The resulting rider animation for the stop.

9.5 Rear

In the two movie files, rear_side.mov and rear_persp.mov, one can view the resulting animations for the rear. The reference for this animation was from the PBS special, Horse and Rider. In figure 44, one will notice that each time the horse lifts his front legs the rider compensates by leaning forward and lifting his seat. Compared to the reference the rider motion is very similar. There are a few differences in that the rider will at times

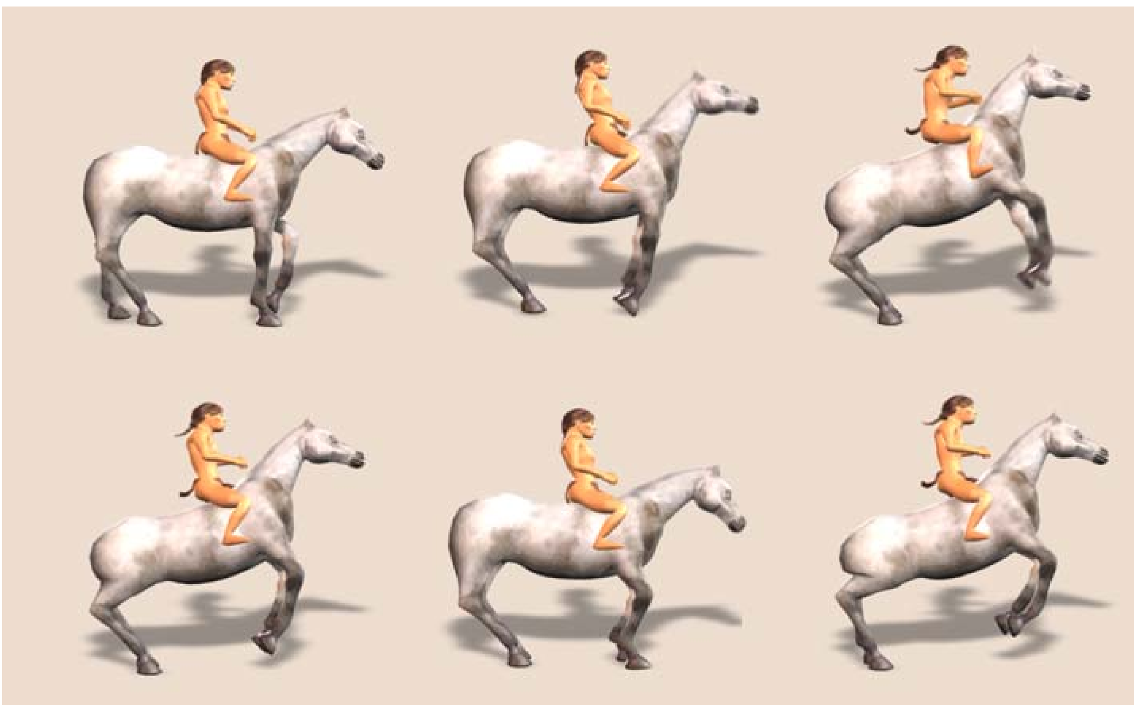

Fig. 44. The resulting rider animation for the rear.

9.6 Walk

In the three movie files, walk_side.mov, walk_persp.mov, and walk_layered.mov, one can view the resulting animations for the walk. The horse's walk was added to test the rider further. Trough the analysis of the reference footage of the walk one will notice that the rider will lean forward as one of the horse's front legs is lifted and set on the ground in front of him. As each leg is lifted and placed in front of him a repetitive rolling motion of the rider is created. The resulting animation accurately simulates this motion.

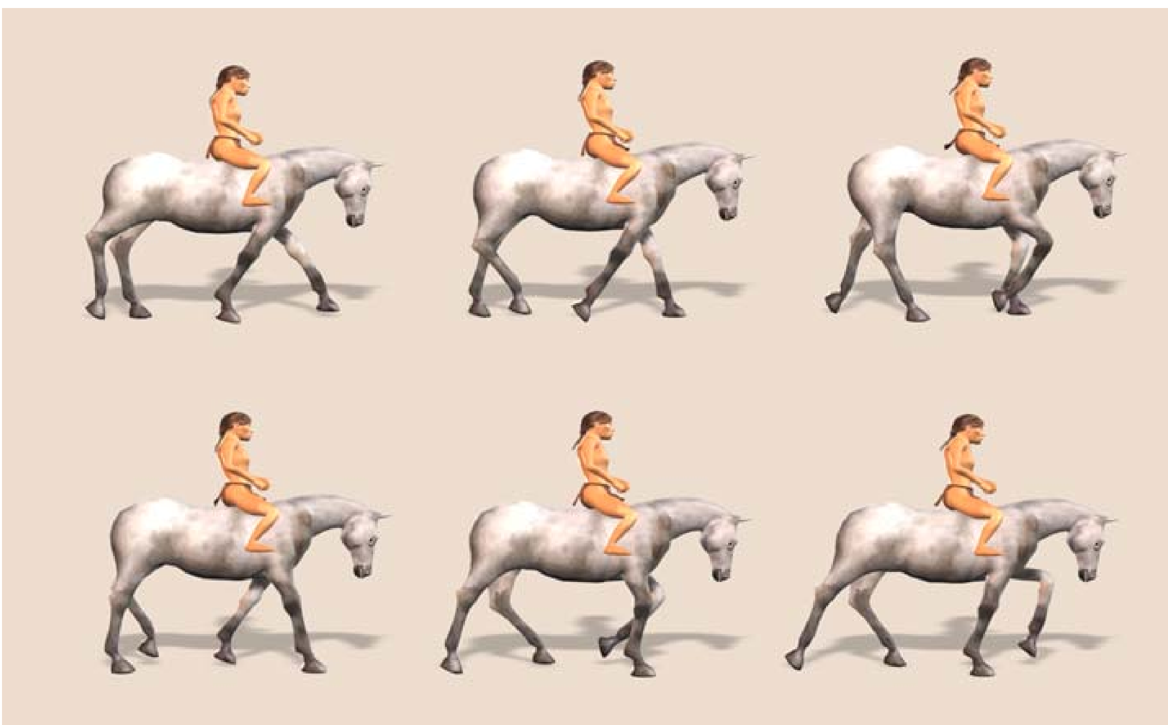

Fig. 45. The resulting rider animation for the walk.

9.7 Bronco Riding

A little bucking bronco motion was animated to test the rider in a very extreme motion. The general motion of the rider was similar to the reference footage from Monte Walsh, but more variables may need to be considered before complete accuracy of the rider's simulation for the bronco riding can be stated.

From the resulting animations demonstrating a variety of different horse and rider movement it can be concluded that the hypothesis was proved. From the animation of the horse a set of expressions involving the analysis of a horse's joint positions were developed to automatically drive correct rider movement. More factors could later be introduced into the equations to take the rider simulation to an even more realistic level, but for now this research provides a great basis to simulating rider movement.

10. IMPLICATIONS FOR FUTURE RESEARCH

The expressions developed by this researcher will be easily transferred to other character rigs involving similar implementations of a horse and rider. For future research one could possibly apply these expressions to other quadruped rigs with a human-like character, such as a dog with a monkey riding on it, or a human on an elephant, zebra, or camel. The more similar the movement between a horse and another animal the easier the expressions could be altered. According to Paul Brown a horse's movement is more similar to heavier animals such as the ox, the elk, the pig, and the buffalo. Lighter quadrupeds like cats, lighter dogs, and deer families have "a more speedy form of locomotion in the series of leaps." [Brown 1943]

Other attributes will have to be considered when trying to apply a horse's movement to another quadruped. In some cases the movement may be too dissimilar. In other cases with a few alterations the scripts may work well. The weight and size of the rider and quadruped will also effect the movement. The rider could be a young child and have a tendency to bounce around more than a fat man inhibiting the horse from galloping too fast. The rider could be inexperienced with less control or an experienced rider displaying good form. In this thesis project general movement was the goal, but for further research one could introduce more control into the scripts that take these factors into consideration. With the complicated nature of humans and quadrupeds, one would suspect many more attributes could be found to perfect the automated motion of a rider.

The research and implementations of this thesis will be a good start in proceeding to other riding situations.

This research made the assumption that the horse and rider were on a flat ground plane. To take on uneven terrain, the expressions will need to be altered. Different types of surfaces could also be considered. In addition, this research is in the direction of the horse’s animation leading the rider, not the rider leading the horse’s movement. It would be interesting to set up a simulation where the user could animate the rider’s directional commands and the horse would be automatically be simulated according to that input. It may be difficult for a non-experienced real world rider to use an animation like this.

This research proves that by adding several expressions that relate the horse and rider movement the rider's movement can be automated. The next step is to allow some variation in the simulated movement.

11. SUMMARY

Through mathematical expressions relating the movement of the horse's joints to the rider's joints the rider's movement was generated. Through observation and research the mechanisms of the horse that drive a rider's movement were found and implemented into a character setup useful to the computer graphics industry. Theses expressions help the animator out with the repetitive and predictable movements of the rider by just animating the horse. Although total realistic motion of a rider is truly hard to achieve just like animating any human or animal motion, this research provides a great start to proceeding to other riding situations. In addition this research is very useful considering one set of mathematical expressions could generate rider movement for such a large amount of horse motion.

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APPENDIX A

The following are descriptions of the Quicktime movie files that show the resulting rider movement for this thesis.

jump_persp.mov - This file shows the generated rider movement in a perspective view of the jump.

jump_side.mov - This file shows the generated rider movement in a side view of the jump.

rear_persp.mov - This file shows the generated rider movement in a perspective view of a rearing horse.

rear_side.mov - This file shows the generated rider movement in a side view of a rearing horse.

stop_close.mov - This file shows the generated rider movement in a close perspective view of the gallop into a stop.

stop_layered.mov - This file shows the generated rider movement next to the reference footage in a side view of the gallop into a stop.

stop_persp.mov - This file shows the generated rider movement in a perspective view of the gallop into a stop.

stop_side.mov - This file shows the generated rider movement in a side view of the gallop into a stop.

trot_close.mov - This file shows the generated rider movement in a close perspective view of the trot.

trot_layered.mov - This file shows the generated rider movement next to the reference footage in a side view of the trot.

trot_persp.mov - This file shows the generated rider movement in a perspective view of the trot.

trot_side.mov - This file shows the generated rider movement in a side view of the trot.

walk_close.mov - This file shows the generated rider movement in a perspective view of the walk.

walk_layered.mov - This file shows the generated rider movement next to the reference footage in a side view of the walk.

walk_persp.mov - This file shows the generated rider movement in a perspective view for the walk.

walk_side.mov - This file shows the generated rider movement in a side view of the walk.

APPENDIX B

Lower Back Rotation Forward and Backward

```
//The height of the horse's feet are used to limit the rider's lower back rotation

//If the height of the rear set is less than 15  and the front set is less than 18
 if (((horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) < 15)
 && ((horse_rig:lfhoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY) < 18))
        {
        //Hores's rear pivot rotation and height off the ground
         rider_rig:lower_back.rotateZ = ((horse_rig:rearPivot.rotateZ
        * ((horse_rig:rearPivot.translateY + 2) * .07))

        //Average position of the horse's back feet forward or back
        + (((horse_rig:rearPivot.translateX) - ((((horse_rig:lbHoofCtrl.translateX)
        + (horse_rig:rbHoofCtrl.translateX ))/2)))* .25)

        //Average position of the horse's front feet forward or back
        + (((horse_rig:rearPivot.translateX) - ((((horse_rig:lfHoofCtrl.translateX)
        + (horse_rig:rfHoofCtrl.translateX))/2))) * -.25)

         //Height of horse's front feet with increased influence according to rear pivot
        + (  ((((horse_rig:lfhoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY)
       * ((abs(horse_rig:rearPivot.rotateZ) + 5) * .1)) * 0.9)

        //Height of horse's back feet
       - ((horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) * 0.4))
       * .40)  );

}

//If the height of the rear set is less than 15 and the front set greater than or equal to 18
//Use 18 in substitution for the height of the horse's front feet
else if (((horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) < 15)
&& ((horse_rig:lfHoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY) >= 18))
{

       rider_rig:lower_back.rotateZ = ( (horse_rig:rearPivot.rotateZ
          * ((horse_rig:rearPivot.translateY + 2) * .07))
          + (((horse_rig:rearPivot.translateX) -  ((((horse_rig:lbHoofCtrl.translateX)
          + (horse_rig:rbHoofCtrl.translateX))/2)))* .25)
          + (((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfHoofCtrl.translateX + 2.5)
```

```
            + (horse_rig:rfHoofCtrl.translateX))/2))) * -.25)
            +  (  ((((18) * ((abs(horse_rig:rearPivot.rotateZ) + 5) * .1)) * 0.9)
            - ((horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) * 0.4))
             * .40) );

}

//If the height of the rear set greater than or equal to 15  and the front set is less than 18
//Use 15 in substitution for the height of the horse's rear feet
else if (((horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) >= 15)
 && ((horse_rig:lfhoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY) < 18))
{

    rider_rig:lower_back.rotateZ =  ( (horse_rig:rearPivot.rotateZ
        * ((horse_rig:rearPivot.translateY + 2) * .07))
        + (((horse_rig:rearPivot.translateX) - ((((horse_rig:lbHoofCtrl.translateX)
        + (horse_rig:rbHoofCtrl.translateX))/2)))* .25)
        + (((horse_rig:nurbsCircle6.translateX) -
         ((((horse_rig:lfHoofCtrl.translateX) + (horse_rig:rfHoofCtrl.translateX))/2)))
         * -.25)
         + (  ((((horse_rig:lfHoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY)
         * ((abs(horse_rig:rearPivot.rotateZ) + 5) * .1)) * 0.9)
         - ((15) * 0.4))  * .40));

}
//else use 15 in substitution for the height of the horse's rear feet and 18 in
//substitution for the height of the horse's front feet
else
{

   rider_rig:lower_back.rotateZ =  ( (horse_rig:rearPivot.rotateZ
         * ((horse_rig:rearPivot.translateY + 2) * .07))
         + (((horse_rig:rearPivot.translateX)
         -    ((((horse_rig:lbHoofCtrl.translateX) + (horse_rig:rbHoofCtrl.translateX))/2)))
         * .25)
         + (((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfhoofCtrl.translateX)
         + (horse_rig:rfHoofCtrl.translateX))/2))) * -.25)   + (  ((((18)
         * ((abs(horse_rig:rearPivot.rotateZ) + 5) * .1)) * 0.9)
         - ((15) * 0.4))  * .40) );
}
```

Lower Back Rotation Side to Side

//Riders lower back rotates in opposite direction the horse twists
rider_rig:lower_back.rotateY = (horse_rig:rearPivot.rotateX x -1);

Lower Back Twist

//Rider twists slightly in direction the waist leans

rider_rig:low_backCTRL.rotateX = rider_rig:waistCTRL.rotateY * .5;

Rider's Waist

//Rider's waist rotates slightly more than the rider's lower back rotation
rider_rig:waistCTRL.rotateZ = (rider_rig:lower_back.rotateZ) * 1.7;

Rider's Hip Rotation Forward and Backward

//Rider's hips move in the same direction as its lower back
rider_rig:hipCTRL.rotateZ = (rider_rig:low_backCTRL.rotateZ * .8);

Rider's Hip Rotation Side to Side

//Hips rotate forward and back according to horse's rear pivot and difference
//in horse's rear feet
rider_rig:hipCTRL.rotateY = ((horse_rig:rearPivot.rotateX) * .5)
   + ((horse_rig:rbHoofCtrl.translateY - horse_rig:lbHoofCtrl.translateY) * 2);

Lift in the Rider's Seat

//Checks to see if the rider's lift is less than or equal to 15
//If it is greater than 15 the rider can not lift any further

//The total distance between the front and back set of feet
if ((((abs(horse_rig:lbHoofCtrl.translateX - horse_rig:rbHoofCtrl.translateX) +
abs(horse_rig:lfHoofCtrl.translateX - horse_rig:rfHoofCtrl.translateX))

//Position of horse's back feet in relation to the translation of horse's rear pivot
+ (((horse_rig:rearPivot.translateX) - ((((horse_rig:lbHoofCtrl.translateX) +
(horse_rig:rbHoofCtrl.translateX))/2))) * -1)

```
    //Position of horse's front feet in relation to the translation of horse's rear pivot
    + ((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfHoofCtrl.translateX ) +
      (horse_rig:rfHoofCtrl.translateX ))/2)))

    //The total height of the horse's front feet
    + ((horse_rig:lfHoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY) * 2)
  ) * .01) <= 15)
{
//Since rider's lift is less than 15 do the following calculation
rider_rig:cogCTRL.translateY = ((

    //The total distance between the front and back set of feet
    (abs(horse_rig:lbHoofCtrl.translateX - horse_rig:rbHoofCtrl.translateX) +
    abs(horse_rig:lfHoofCtrl.translateX - horse_rig:rfHoofCtrl.translateX) )

    //Position of horse's back feet in relation to the translation of horse's rear pivot
    + (((horse_rig:rearPivot.translateX) -  ((((horse_rig:lbHoofCtrl.translateX) +
      (horse_rig:rbHoofCtrl.translateX ))/2))) * -1)

    //Position of horse's front feet in relation to the translation of horse's rear pivot
    + ((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfHoofCtrl.translateX ) +
      (horse_rig:rfHoofCtrl.translateX ))/2)))

    //The total height of the horse's front feet
    + ((horse_rig:lfHoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY) * 2) ) * .01);
}

//else the rider's lift is limited to 15
else{ rider_rig:cogCTRL.translateY = 15; }
```

Rider's Shift in Seat

```
//Limits the rider's translation to be no more than 1
if (((((horse_rig:rearPivot.rotateZ) * 2) - rider_rig:waistCTRL.rotateZ)* 0.1) >1)

    //Rider's translation forward equals 1
    {rider_rig:cogCTRL.translateX = 1; }

//Limits the rider's translation to be no more less than - 1
else if (((((horse_rig:rearPivot.rotateZ) * 2)
      - rider_rig:waistCTRL.rotateZ) * 0.1) < -1)

      //Rider's translation backward equals -1
```

```
        {rider_rig:cogCTRL.translateX = -1;}

//If the rider's translation is between 1 and –1 do the following calculation
else
    //Rider's translation forward and backward according to horse's rear pivot
   //and rider's lower back rotation forward and back
   {rider_rig:cogCTRL.translateX = (((horse_rig:rearPivot.rotateZ) * 2)
    -    rider_rig:lower_back.rotateZ)* 0.1;}
```

Squash and Stretch

```
//Each joint takes the original joint position plus a fraction of the rider's lift
rider_rig:cl_spinecJNT.translateY = 0.482 - .1 + ((rider_rig:cogCTRL.translateY)/6);
rider_rig:cl_spinedJNT.translateY = 0.564 - .1 + ((rider_rig:cogCTRL.translateY)/6);
rider_rig:cl_spinefJNT.translateY = 0.949 - .1 + ((rider_rig:cogCTRL.translateY)/6);
rider_rig:cl_neckJNT.translateY = 1.392 - .1 + ((rider_rig:cogCTRL.translateY)/7);
rider_rig:cl_headaJNT.translateY = 1.002 - .1 + ((rider_rig:cogCTRL.translateY)/7);
```

Rider's Head Rotation Side to Side

```
//Rider's head rotation side to side in same direction as horse's twist
rider_rig:headCTRL.rotateY = (horse_rig:rearPivot.rotateX * .8);
```

Rider's Wrist Translation forward and backward

and head rotation forward and backward

```
//Since the wrist translation and head rotation depend on the rider's lower back rotation
//this can be used to limit the amount of translation and rotation there is in the rider's
//wrists and head

//If the rider's lower back rotation is greater than –17 degrees and less than 17 degrees
if ((rider_rig:low_backCTRL.rotateZ < 17)
&& (rider_rig:low_backCTRL.rotateZ > -17))
      {
       //Calculate rider's right wrist translation forward and backward
       rider_rig:rt_wrist_locator.translateZ = (rider_rig:lower_back.rotateZ * .0001)
      - (  ((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfHoofCtrl.translateX ) +
      (horse_rig:rfHoofCtrl.translateX))/2))) * (abs(horse_rig:rearPivot.rotateZ)
       * .008)  ) ;
```

```
        //Calculate rider's left wrist translation forward and backward
        rider_rig:lf_wrist_locator.translateZ = (rider_rig:lower_back.rotateZ * .0001)
        - (  ((horse_rig:rearPivot.translateX) -  ((((horse_rig:lfHoofCtrl.translateX ) +
        (horse_rig:rfHoofCtrl.translateX))/2))) * (abs(horse_rig:rearPivot.rotateZ)
         * .008)  ) ;

        //Calculate rider's head rotation forward and backward according
        //to rider's lower back rotation and lift of the rider
        rider_rig:headCTRL.rotateZ = (-rider_rig:lower_back.rotateZ * .9) -
        ((rider_rig:cogCTRL.translateY) * 18) + 5;
        }

//If the rider's lower back greater than or equal to 17 degrees use 17 degrees
// for the lower back rotation in the equation
else if (rider_rig:low_backCTRL.rotateZ >= 17)
{

        rider_rig:rt_wrist_locator.translateZ = (-17 * .0001) –
        (  ((horse_rig:rearPivot.translateX) -    ((((horse_rig:lfHoofCtrl.translateX)
        + (horse_rig:rfHoofCtrl.translateX))/2)))
        * (abs(horse_rig:rearPivot.rotateZ)* .008)  ) ;


        rider_rig:lf_wrist_locator.translateZ = (-17 * .0001) –
        (  ((horse_rig:rearPivot.translateX) -    ((((horse_rig:lfHoofCtrl.translateX)
        + (horse_rig:rfHoofCtrl.translateX))/2)))
        * (abs(horse_rig:rearPivot.rotateZ)* .008)  ) ;


        rider_rig:headCTRL.rotateZ = (-17 * .9) - ((rider_rig:cogCTRL.translateY)  * 18)
        + 5;
}

//If the rider's lower back less than or equal to -17 degrees use -17 degrees
// for the lower back rotation in the equation
else if (rider_rig:low_backCTRL.rotateZ <= -17)
{

          rider_rig:rt_wrist_locator.translateZ = (17 * .0001)
          -  (  ((horse_rig:rearPivot.translateX) - ((((horse_rig:lfHoofCtrl.translateX)
          + (horse_rig:rfHoofCtrl.translateX))/2))) * (abs(horse_rig:rearPivot.rotateZ
          - 0.572)* .008)  ) ;
```

```
        rider_rig:lf_wrist_locator.translateZ = (17 * .0001)
        -  (  ((horse_rig:rearPivot.translateX) - ((((horse_rig:lfHoofCtrl.translateX)
        + (horse_rig:rfHoofCtrl.translateX))/2))) * (abs(horse_rig:rearPivot.rotateZ
        - 0.572)* .008)  ) ;

        //If the rider's lower back less than or equal to -20 degrees use -20 degrees
        // for the lower back rotation in the equation of the rider's head rotation.
        //This gives the rider the ability to rotate his head a little more forward for
        // a case like the stop
        if (rider_rig:low_backCTRL.rotateZ <= -20)
        {
                rider_rig:headCTRL.rotateZ = (20 * .9)
                 - ((rider_rig:cogCTRL.translateY) * 18) + 5;
        }
        else
        {
                rider_rig:headCTRL.rotateZ = (-rider_rig:low_backCTRL.rotateZ * .9)
                - ((rider_rig:cogCTRL.translateY) * 18) + 5;
        }

}
```

Rider's Wrist Translation Up and Down

```
//Limits the rider's wrist translation by monitoring the height of the horse's feet
//If the height is less than 20 monitor the horse's feet and rear rotational pivot

if ((horse_rig:lfhoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY
 + horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) < 20)
{
            //Calculate the rider's right wrist translation forward and backward
            rider_rig:rt_wrist_locator.translateY = ((horse_rig:lfHoofCtrl.translateY
            + horse_rig:rfHoofCtrl.translateY + horse_rig:lbHoofCtrl.translateY
            + horse_rig:rbHoofCtrl.translateY) * 0.03)
            - ((horse_rig:rearPivot.translateY) * .0005);

            //Calculate the rider's left wrist translation forward and backward
            rider_rig:lf_wrist_locator.translateY = ((horse_rig:lfHoofCtrl.translateY
            + horse_rig:rfHoofCtrl.translateY + horse_rig:lbHoofCtrl.translateY
            + horse_rig:rbHoofCtrl.translateY) * 0.03)
            - ((horse_rig:rearPivot.translateY ) * .0005);
}
//Else substitute 20 in for the height of the horse's feet in the equation
else
```

```
{
    //Calculate the rider's right wrist translation forward and backward
    rider_rig:rt_wrist_locator.translateY = (20 * 0.03)
    - ((horse_rig:rearPivot.translateY ) * .0005);
    //Calculate the rider's left wrist translation forward and backward


    rider_rig:lf_wrist_locator.translateY = (20 * 0.03)
    - ((horse_rig:rearPivot.translateY) * .0005);
}
```

Rider's Foot Twist, Foot Rotation Side to Side, and Foot Translation Towards and Away From the Horse

```
//Limits the rotation and translation of the rider's feet by the height of the horse's feet

//If the sum of the height of the horse's feet is less than 15
if ( (horse_rig:lfhoofCtrl.translateY + horse_rig:rfHoofCtrl.translateY
   + horse_rig:lbHoofCtrl.translateY + horse_rig:rbHoofCtrl.translateY) <= 15)
   {

   //Rotation of rider's right foot twist
   rider_rig:rt_footCTRL.rotateY = (((horse_rig:lfHoofCtrl.translateY
   + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
   + horse_rig:rbHoofCtrl.translateY)) * -1.7) - 1;

   //Rotation of rider's left foot twist
     rider_rig:lf_footCTRL.rotateY = (((horse_rig:lfHoofCtrl.translateY
   + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
   + horse_rig:rbHoofCtrl.translateY)) * -1.7) - 1;

   //Rotation of rider's right foot side to side
   rider_rig:rt_footCTRL.rotateX = (((horse_rig:lfHoofCtrl.translateY
   + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
   + horse_rig:rbHoofCtrl.translateY)) * -0.1) + 1;

   //Rotation of rider's left foot side to side
   rider_rig:lf_footCTRL.rotateX = (((horse_rig:lfHoofCtrl.translateY
   + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
   + horse_rig:rbHoofCtrl.translateY)) * 0.1) + 1;
```

```
    //translation of the right foot towards and away from the horse
    rider_rig:rt_footCTRL.translateX = (((horse_rig:lfHoofCtrl.translateY
    + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
    + horse_rig:rbHoofCtrl.translateY)) * -0.05) + 2
    - (horse_rig:rearPivot.rotateX * .05);

    //translation of the left foot towards and away from the horse
    rider_rig:lf_footCTRL.translateX = (((horse_rig:lfHoofCtrl.translateY
    + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
    + horse_rig:rbHoofCtrl.translateY)) * -0.05) + 2
    - (horse_rig:rearPivot.rotateX * .05);

    //Rider's left knee translation up and down
    rider_rig:lf_kneeCTRL.translateY = (((horse_rig:lfHoofCtrl.translateY
    + horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
    + horse_rig:rbHoofCtrl.translateY)) * 0.03) - 1;

    //Rider's right knee translation up and down
     rider_rig:rt_kneeCTRL.translateY = (((horse_rig:lfHoofCtrl.translateY
    + horse_rig:rfHoofCtrl.translateY + horse_rig:lbHoofCtrl.translateY
   + horse_rig:rbHoofCtrl.translateY)) * 0.03) - 1;
}

//else substitute 15 for the sum of the height of the horse's feet
// to limit the foot movement

else
{
//Rotation of rider's right foot twist
rider_rig:rt_footCTRL.rotateY = (((15)) * -1.7) - 1;

//Rotation of rider's left foot twist
rider_rig:lf_footCTRL.rotateY = (((15)) * 1.7) + 1;

 //Rotation of rider's right foot side to side
rider_rig:rt_footCTRL.rotateX = (((15)) * -0.1) + 1;

 //Rotation of rider's left foot side to side
rider_rig:lf_footCTRL.rotateX = (((15)) * 0.1) + 1;

 //translation of the right foot towards and away from the horse
rider_rig:rt_footCTRL.translateX = (((15)) * -0.05) + 2
    - (horse_rig:rearPivot.rotateX * .05);
```

```
//translation of the left foot towards and away from the horse
rider_rig:lf_footCTRL.translateX = (((15)) * 0.05) - 2
      - (horse_rig:rearPivot.rotateX * .02);

//Rider's left knee translation up and down
rider_rig:lf_kneeCTRL.translateY = (((15)) * 0.03) - 1;

//Rider's right knee translation up and down
rider_rig:rt_kneeCTRL.translateY = (((15)) * 0.03) - 1;
}
```

Rider's Foot Translation Forward and Backward

```
//Need to limit the rider's feet from translating too far forward
//if the rider's foot translation is backward
if (( ((horse_rig:rearPivot.translateX) -
      ((((horse_rig:lfHoofCtrl.translateX ) + (horse_rig:rfHoofCtrl.translateX))/2)))
       * -((abs(horse_rig:rearPivot.rotateZ) * .005) + .08
      + (horse_rig:backMid.rotateZ * .02)) ) <= 0)

         {
         //Rider's foot position according to horses' front foot position forward or back
         //horse's rear pivot rotation and rider's lower back rotation
         rider_rig:lf_footCTRL.translateX = ((horse_rig:rearPivot.translateX)
               - ((((horse_rig:lfHoofCtrl.translateX ) + (horse_rig:rfHoofCtrl.translateX
                ))/2))) *  -((abs(horse_rig:rearPivot.rotateZ) * .005) + .08
               + (horse_rig:backMid.rotateZ * .02))  -(abs(horse_rig:rearPivot.rotateZ)
               * rider_rig:lower_back.rotateZ * .005);

         rider_rig:rt_footCTRL.translateX = ((horse_rig:rearPivot.translateX)
               - ((((horse_rig:lfHoofCtrl.translateX ) + (horse_rig:rfHoofCtrl.translateX
                ))/2))) *  -((abs(horse_rig:rearPivot.rotateZ) * .005) + .08
               + (horse_rig:backMid.rotateZ * .02))  -(abs(horse_rig:rearPivot.rotateZ)
               * rider_rig:lower_back.rotateZ * .005);

}
//Else if foot translation is forward
else
      {  rider_rig:lf_footCTRL.translateX = 0 - (abs(horse_rig:rearPivot.rotateZ - 0.572)
            *  rider_rig:lower_back.rotateZ * .005);

      rider_rig:rt_footCTRL.translateX = 0 - (abs(horse_rig:rearPivot.rotateZ - 0.572)
            * rider_rig:lower_back.rotateZ * .005);    }
```

Rider's Foot Rotation Up and Down

//Rider's foot rotates up as the foot translates forward and down as it translates back

```
rider_rig:rt_footCTRL.rotateZ = (((rider_rig:lf_footCTRL.translateX + 3) * -6 ) * 2);
rider_rig:lf_footCTRL.rotateZ= (((rider_rig:lf_footCTRL.translateX  + 3)* -6 ) * 2);
```

Rider's knee translation

//Rider's knee translation opposite the direction of the rider's foot translation
//towards and away from the horse

```
rider_rig:rt_kneeCTRL.translateZ = initial position – (rider_rig:lf_footCTRL.translateZ)
   * 1.1;

rider_rig:lf_kneeCTRL.translateZ= initial position – (rider_rig:lf_footCTRL.translateZ)
   * 1.1;
```

Rider's Hair and Cloth

//Braid up and down controlled by height of horse's feet

```
rider_rig:hair_control.Riding_hair = ((horse_rig:lfHoofCtrl.translateY
+ horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
+ horse_rig:rbHoofCtrl.translateY)- 2) * 0.7;
```

//Braid side to side controlled by height of horse's feet and rider's lower back rotation

```
rider_rig:hair_control.braid_side_to_side = ((horse_rig:lfHoofCtrl.translateY
+ horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
+ horse_rig:rbHoofCtrl.translateY)- 2) * rider_rig:waistCTRL.rotateY * -.02;
```

//Cloth up and down controlled by height of horse's feet

```
rider_rig:Cloth_control.cloth_up = ((horse_rig:lfHoofCtrl.translateY
+ horse_rig:rfHoofCtrl.translateY  + horse_rig:lbHoofCtrl.translateY
+ horse_rig:rbHoofCtrl.translateY)- 2) * 0.7;
```

//Cloth side to side controlled by height of horse's feet and horse's rear pivot rotation

```
rider_rig:Cloth_control.blow_side_to_side = ((horse_rig:rearPivot.rotateX ) * -.5) +
((horse_rig:rbHoofCtrl.translateY - horse_rig:lbHoofCtrl.translateY) * -2);
```

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