PROCEDURAL ANIMATION OF EMOTIONALLY EXPRESSIVE GAZE SHIFTS IN VIRTUAL EMBODIED CHARACTERS

by

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Epigraph

"The eyes are the most important part of an expression, and must be drawn with extreme care. Any jitter or false move on an inbetween destroys both communication and believability."

-Frank Thomas and Ollie Johnston

The Illusion of Life

Dedication

I dedicate this thesis to Dr. Jeff Rickel, who would have loved it.

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Abstract

Believably animated virtual human characters appear in many diverse fields of computer science research and areas of the technology industry, including video games, animated films, and virtual training environments. In these applications, animated virtual humans play roles ranging from friendly companions, to helpful tutors, to vicious villains. A key aspect that distinguishes these applications is user interaction. In video games and virtual training environments, interaction between virtual human characters and human users is required, in contrast to animated films. However, the animation methods that produce often very believable behavior for these animated films do not apply well to interactive domains. This leads to an expressivity gap between those animated virtual humans which are interactive and those which are not.

One ability that non-interactive animated characters possess and interactive characters do not is the ability to reveal important information about their emotional state through the use of glances or glares while the character remains silent. The goal of this research is to provide this ability to interactive characters. It does so through a gaze model capable of displaying a desired selection of physical behaviors while directing gaze towards an arbitrary target. This model of gaze, called the Expressive Gaze Model (EGM), combines body movement based on motion capture data with eye movement based on visual neuroscience data.

In addition, this research provides an empirically determined preliminary mapping between gaze behavior and emotional attribution. The results demonstrate

that by obtaining a set of low-level gaze behaviors annotated with emotional data, and then generating gaze shifts through the composition of these low-level behaviors, the attribution of emotion to the resulting gaze shift can be predicted. This indicates that gaze shifts that display emotion states can be generated from these low-level gaze behaviors without using motion capture of the displayed emotion.

Chapter 1 Introduction

1.1 Motivation

Believably animated virtual human characters appear in many diverse fields of computer science research and areas of the technology industry. For example, they appear in applications as diverse as Embodied Conversational Agents that interact with and attempt to develop relationships with humans [Bickmore & Picard, 2005], Pedagogical Agents in tutoring systems [Rickel & Johnson, 1999], human-controlled avatars in applications such as virtual reality or online games [Vilhjalmsson & Cassell, 1998], simulated humans in virtual environments [Shao & Terzopoulos, 2005], interactive computer-controlled characters in video games, and even as characters in pre-rendered computer graphic videos. In these applications, animated virtual humans play roles ranging from friendly companions, to helpful tutors, to vicious villains.

Unfortunately, the methods used for animating characters in pre-rendered video often provide more believable and expressive movement than do the methods used for animating interactive characters. Characters in pre-rendered feature films can come alive, enthrall audiences and critics, and even win Oscar awards, while interactive virtual characters do not. This is because each movement in a pre-rendered film is deliberately and carefully crafted, placed, and synchronized with the sound and surrounding environment in a process that can take hours or days. This luxury is not available to characters in a dynamic interactive environment.

This gap in expressiveness between interactive and pre-rendered human characters is not an idle concern. [Silverman, 2004] points out that virtual humans with more realistic behavior and cognition can improve sales of commercial products and provide benefits to systems with military application. There have been previous attempts to address this gap. These attempts have led researchers to add capabilities such as facial expression [Pelachaud & Poggi, 2002], increasingly realistic voices [Douglas-Cowie et al., 2003], head movement [Busso et al., 2005], and gesture [Kipp et al., 2007] to interactive virtual characters. Despite these additional capabilities, the expressivity gap between interactive and pre-rendered characters remains.

One reason for the continued expressivity gap between interactive and pre-rendered characters is that interactive characters lack "expressive gaze manner." A model of expressive gaze manner manipulates the way in which a gaze shift – a complex set of behaviors that can include eye, head, or posture movement, and even stepping or standing – is performed, in order to display behaviors that an observer will attribute emotional content to.

The goal of this work is to address this expressivity gap by enabling virtual interactive characters to perform gaze shifts that display behaviors that observers will attribute emotion to – even though this may not necessarily be behavior that a human feeling the same emotion would produce.

1.1.1 Importance of Gaze

The necessity of a model of expressive gaze manner in developing a realistic animated human figure can be seen in the ability of humans and of pre-rendered animated characters to reveal important information about their emotional state through the use of glances or glares while they remain silent. This shows that the *manner* of a person's gaze – changes in physical parameters of individual movements, such as the velocity of the head in a single gaze shift, distinct from changes in specific properties like the target or time of occurrence of a gaze shift – reveals much about their inner state and intent.

Unfortunately, while gaze is an important aspect of nonverbal behavior, producing believable and expressive gaze is a very difficult problem. The primary reason for this is that mistakes which are made in the eye are immediately disconcerting to the viewer, causing a robotic and unnatural impression of the character. The importance of both appropriate manner for gazing behaviors and of appropriate interrelations between eye and head movement can be seen in a number of virtual human designs, as well as in some computer graphic animated films.

As an example, consider the film "The Polar Express," in which the characters were animated through motion capture; except for the eyes, which were separately hand-animated. One reviewer noted "Although the human characters look about 90% lifelike, it is that darn 10% (mostly the lifeless eyes) that winds up making them seem really creepy," [Sobczynski, 2004]. Other reviewers agreed, describing unnatural eyes, and referring to the animated characters as "zombies" or "creepy." This supports the argument made in [Thomas & Johnston, 1981] that "the eyes are the most important part of an expression, and must be drawn with extreme care. Any jitter or false move … destroys both communication and believability."

1.2 Research Question

The research question addressed by this thesis is: "How can emotions be expressed through gaze by a real-time interactive virtual character?" The answer provided to this question is composed of two parts. The first is a model of gaze which takes into account eye, head, and torso movement; and that can be used to express emotion. Second, that model is used to investigate the relationship between gaze behaviors and attributed emotional state, in order to minimize the amount of data collection necessary to produce emotionally expressive gaze.

1.3 Approach – Gaze Model

There are many methods for animating virtual human characters. The pre-rendered virtual characters appearing in computer graphic feature films are generated primarily through either key framing – the generation of animation by hand-producing individual key frames, and interpolating between those frames to produce movement – or through motion capture, where the movement of an actual actor is recorded and used to drive the animated character.

However, the animation methods used to produce the virtual characters in pre-rendered video do not apply well to interactive domains. This is because the animated movements generated through these approaches consist of long, static, atomic blocks of movement that tend to be believable and applicable only within the scripted set of circumstances the movement was generated to address. They are not interruptible and difficult to reuse. In addition, these methods (particularly key framing) are expensive and time-consuming to generate such that it would be prohibitive in time and cost to obtain the large library of movements which would be necessary to implement an interactive system using these techniques.

To address this desire for interactive animation, alternative methods of producing animation have been developed. [Rose et al., 1998] categorize these methods into three broad categories: procedural, simulated, and interpolated. Procedural animations are those that are generated algorithmically such as [Pelachaud & Bilvi, 2003], while simulated animations are produced by simulating the biomechanics of the human body in combination with the physical properties of the real world [Lee & Terzopoulos, 2006]. Finally, interpolated animations are produced by interpolating between sequences of motion captured or key framed animation to generate new desired movements [Rose et al., 1998].

Unfortunately, each of these animation methods provides its own drawbacks. Procedural methods are the most versatile in virtual environments, but often provide animation that is lower in quality. Simulated methods provide high quality animation, but require intensive computation and are only usable in limited circumstances. Motion capture interpolation can also provide high-quality animation, but with less versatility than procedural methods.

To address this, this work describes a model of gaze, the Expressive Gaze Model (EGM). It combines two parts: the first part is a motion capture based animation method, the Gaze Warping Transformation (GWT), that drives a character's head and torso movement [Lance & Marsella, 2007], and the second is a procedural animation method that produces eye movement [Lance & Marsella, 2008a].

There are several benefits to this approach. By combining an animation method based on motion capture with a procedural animation method, high quality animation that produces gaze shifts to desired targets while displaying arbitrary behavior can be obtained. In addition, the gaze movement is based firmly in human behavior by generating the head and torso movement with motion capture data, and drawing both the model of eye movement – and the integration of eye movement and the motion capture – from work in the visual neuroscience literature, such as [Leigh & Zee, 2006].

1.4 Approach – Emotion/Behavior Mapping

This work also uses the Expressive Gaze Model to explore the relationship between a space of physical gaze behaviors, and a space of emotions [Lance & Marsella, 2008b]. Specifically, the question explored is: "Is there a relationship between the composition of low-level gaze behaviors into complex, expressive gaze shifts, and the composition of low level emotional dimensions into complex emotional states such that it can be reliably predicted how a viewer will attribute emotion to a gaze shift generated by composing low level behaviors?"

The purpose of this exploration is to produce emotionally expressive gaze shifts with a minimum of motion capture data. The most intuitive way to utilize the EGM would be to have motion capture data for each desired emotional state, and then use that data to generate an expressive gaze shift to a desired target. However, this method only allows the model to generate emotional gaze in a pinpoint, nearest-neighbor fashion. It also requires motion captures for each emotional state, which may be difficult to obtain; and it does not predict the attribution of emotion to behaviors outside of these specific emotional states. Instead, an approach similar to the "reverse engineering" approach of [Grammer & Oberzaucher, 2006] was adopted. The goal of this approach is to find a set of low level gaze behaviors, annotated with emotional data, which can be combined according to a dimensional model of emotion into complex gaze movements revealing complex emotional states. In this way, a broader array of emotional responses can be generated while using a smaller library of GWTs derived from a smaller number of motion captures.

1.5 Major Contributions

This thesis has several contributions:

- The Expressive Gaze Model: The first model for realizing expressive gaze in interactive virtual characters.
- The EGM is also the first model of animation that blends a neuroscience-based procedural model of animated eye movement with a motion-capture based animation model.
- The model also provides an approach to transforming physical behaviors into emotionally expressive physical behaviors that may generalize beyond gaze.
- Also contributed is a preliminary mapping between composed emotional dimensions and composed low-level gaze behaviors.

1.6 Thesis Outline

The remainder of the dissertation will be organized as follows:

- Chapter 2 – Related Work
- Chapter 3 – The Gaze Warping Transformation
- Chapter 4 – The Procedural Eye Model
- Chapter 5 – Mapping Between Behaviors and Emotions
- Chapter 6 – Conclusion

Chapter 2 Related Work

2.1 Overview

In this chapter, three broad categories of related work are discussed. The first section covers the field of nonverbal behavior research and other sources of information regarding physical behavior; primarily sources regarding emotional display through gaze and natural gaze behavior. In addition, the psychology literature on how emotions are displayed through head movement and torso posture is discussed, as gaze includes more than just the movement of the eyes. Second, research on the realization of gaze behavior in Embodied Conversational Agents and Virtual Avatars is examined; and finally, there is a discussion of work on the generation and transfer of expressive manner for animated physical behavior.

2.2 Gaze

Gaze itself has many uses in human interaction. For example, gaze is used to regulate the interaction between individuals (an overview is provided in [Heylen, 2005a]), such as through turn-taking behaviors [Kendon, 1990], or "cut-off" behaviors when interaction is not desired [Givens, 1981]. Gaze can also be used to signal communicative acts [Poggi et al., 2000], [Poggi & Pelachaud, 2001], such as the introduction of new information into a conversation [Cassell et al., 1999].

2.2.1 Expression of Emotion through Gaze

While much of the research on gaze focuses on communicative signals and the modeling of attention, this work is focused on how gaze is used to display internal affective attitudes and notions, specifically those related to the PAD model [Mehrabian, 1981] dimensions of pleasure/displeasure, arousal/relaxation, and dominance/submissiveness. The PAD model is utilized for this research because it is composed of a manageable number of dimensions, each of which has a background of research describing gaze and other physical behaviors associated with it.

For example, the importance of gaze in signaling dominance cannot be overstated. While there are other nonverbal behaviors used in the display of dominance, [Cashdan, 1998], the importance of gaze can be seen in experiments where a human experimenter provokes dominance displays in animals simply by staring at them [Exline, 1974]. Unfortunately, the relationship between gaze and dominance is complex and not fully understood [Exline, 1974], [Kleinke, 1986], [Argyle & Cook, 1976], [Mehrabian & Ksionzky, 1974]. One finding is that dominant individuals tend to look less while listening and more while speaking over the course of a conversational interaction than do less dominant individuals [Knapp & Hall, 1997], [Ellyson et al., 1981]. Despite the complexity of the gaze-dominance relationship, the focus of this work is on the attribution of emotion to physical behavior. [Carney, 2005] describes the widespread beliefs about how dominance is displayed through gaze. For example, dominance is attributed to stares and increased gaze, while submissiveness is attributed to averted gaze.

Gaze is also closely related to arousal. Receiving gaze or engaging in mutual gaze actually increases physiological arousal [Kendon, 1990]. So the pattern of gaze depends on the desired arousal state of the individual gazing, in addition to their actual arousal state [Argyle & Cook, 1976]. However, increased blinks and increased pupil dilation are both strong signals of arousal [Knapp & Hall, 1997], [Mehrabian, 1981].

Evidence for the relationship of gaze to the display of pleasure/displeasure is more limited. In fact, some have argued that gaze is incapable of displaying emotional valence, as reported in [Kleinke, 1986]. However, others, such as [Merten, 1997] have found correlations between self-reported expressions of joy vs. sadness and the percentage of mutual gaze in an interaction.

2.2.2 Head Movement

While the focus in this work is on the attribution of emotion to head movement, much of the movement of the head is directly related to verbal conversation [Heylen, 2005b], [McClave, 2000]. For example [Hadar et al., 1985], found that head movements which were synchronized with speech had different properties than head movements which anticipated speech. Analyzing head movement in regard to gaze is further complicated by the fact that the movement of the head also affects the movement of the eyes [Freedman & Sparks, 2000].

However, the display of an individual's emotional state can be affected by whether their head is turned upwards or downwards. [Kappas et al., 1994], showed photographs of facial expressions from different viewing angles to observers, and found that subjects facial expressions were rated as more positive, and less negative when viewed from below (as if the subject was looking upwards), and more negative and less positive when viewed from above. While they did not find any effect of viewing angle on the expression of dominance, [Mignault & Chaudhury, 2003], performed a similar experiment, and did find a strong dominance effect. Specifically, [Mignault & Chaudhury, 2003] found that a bowed head connoted submission and sadness, while a raised head was viewed as dominant and happy.

2.2.3 Visual Neuroscience

In addition to understanding how emotion is conveyed through eye and head movement, an understanding of the natural behavior of the eyes and their relationship to the head is needed to function as the basis of a model of gaze. If a model of eye movement does not conform to natural behavior, there is a risk of producing antipathy towards any virtual agent using the unnatural eye behaviors. As described in [Leigh & Zee, 2006], the eye has a limited number of functional classes of eye movements, including vestibular, visual fixation, smooth pursuit, and saccadic movements.

While knowing how emotion is attributed to various volitional saccades would be valuable; saccadic movements are highly stereotypical because of the close relationship between saccade amplitude, duration, and velocity, known as the main sequence relationship [Leigh & Zee, 2006]. As saccades are highly stereotyped movements, the expression of emotion through saccades will occur through the timing of the saccade, the target of the saccade, and the movement of the head and torso during the saccade, not through variation of the saccade itself.

The visual neuroscience literature also contains information describing the relationship between head movement and eye movement during gaze shifts [Uemura et al., 1980]. For example, during a large gaze shift, the head will also perform saccadic movement. During this head movement, the eye saccades will be performed in a highly constrained fashion, and both the eye and the head function according to their separate main sequence relationships. However, the head movement has a large amount of variability [Zangemeister et al., 1981], as does the head main sequence relationship. In contrast, the eyes follow a specific pattern. During a gaze shift that contains a head saccade, the eyes will saccade to the gaze target, or to the extent of vision. Then, as the head turns to the target, the eyes will turn back towards the center [Zangemeister et al., 1981], [Leigh & Zee, 2006]. The presence of saccadic head movement also depends on the amplitude of the gaze. In monkeys, gaze shifts of less than twenty degrees tend to be eyes only. Once the gaze shift is larger than thirty degrees, the eye movement reaches a soft limit, and then the saccadic head movement begins to take place [Phillips et al., 1995].

The velocity of the eyes during a gaze shift is also dependent on the head movement. [Freedman & Sparks, 2000] showed that the velocity curves of eye saccades during head movement are different from the curves of eye saccades performed while the head is stationary. Specifically, gaze shifts with higher amplitude head movements will have saccade velocity curves that are broader, lower amplitude, and double-peaked whereas similar amplitude gaze shifts with lower amplitude head movement will have narrower, higher amplitude, single peaked saccade velocity curves.

2.2.4 Posture

Posture – the orientation of the trunk of the body – is an important channel for displaying behavior that emotion is commonly attributed to. While there has been work showing that an upright posture is viewed as a display of dominance, in contrast to viewing a bowed forward posture as a display of submission [Mehrabian, 1981], [Carney, 2005], most of the research into posture has used emotional categories such as "anger" or "fear" as opposed to emotional dimensions such as those in the PAD model of emotion. Additionally, much of the research on posture involves generating static images of various postures, and displaying those to coders, such as [Schouwstra & Hoogstraten, 1995] and [Coulson, 2004] – who also examined the effect of viewpoint on recognition. Instead of using emotional categories, [Grammer et al., 2004] generated a set of postures from a large space of possible postures, and had coders rate them using an affect questionnaire that measured factors such as social aversion and social openness.

There has also been research exploring how emotion is attributed to changes in posture, such as [Montepare et al., 1999], who explored how different age groups emotionally rated different postures; [de Meijer, 1989], who showed videos of body movement to observers, and examined how various types of trunk and arm movement, as well as the force, velocity, and directness of the movement were related to different emotional attribution by viewers; and [Wallbott, 1998], who examined the encodings of various emotional states by actors, looking for how emotion was encoded in the posture and movement of the actors.

2.2.5 Other Sources of Information on Nonverbal Behavior

There are additional sources of information on nonverbal behavior than the study of nonverbal behavior in Psychology. For example, the bible of traditional 2D animation, [Thomas & Johnston, 1981], contains information about how eye movement and the shape of the eyes is used to display emotions, and [Lasseter, 1987] describes how the principles of animation set forth by Thomas and Johnston can be applied to 3D computer animation as well.

Choreography is also a field closely concerned with demonstrating character and emotion through movement. Two of the more well-known choreographers with movement description systems are Rudolph Laban, and Francoise Delsarte, who took very different approaches to the description of movement. Francoise Delsarte was a French choreographer in the mid 1800's who developed an expansive system that attempted to codify all possible meanings and uses of each individual movement of the human body [Shawn, 1963]. Laban, on the other hand developed a hierarchical taxonomy of movements, classifying them based on four main categories: Body, Effort, Shape, and Space, each with several sub-categories [Newlove & Dalby, 2004].

2.3 Realization of Nonverbal Behavior

There have been many implementations of gaze behaviors in real-time applications, such as Embodied Conversational Agents. One of the first of these was Animated Conversation [Cassell et al., 1994], which implemented a real-time interaction between two virtual agents. The gaze model did not differentiate eye movement from head movement, and was based on conversational behaviors such as turn taking, but it demonstrated the possibility of virtual characters using gaze as a communicative signal. Many gaze implementations in virtual characters are similarly based on communicative signals (e.g. [Heylen et al., 2005], [Bickmore & Cassell, 2004]). For example, [Pelachaud & Bilvi, 2003], use Bayesian belief nets to determine when to gaze based on frequency data collected from human interaction [Cappella & Pelachaud, 2002]. Other gaze models have been developed for agents which perform tasks other than or in addition to interaction with other characters or users, such as [Chopra-Khullar & Badler, 1999], or [Gillies & Dodgson, 2002]. The Steve agent [Rickel & Johnson, 1999] tutors a student on how to use a virtual factory environment. Steve's gaze is based on monitoring the environment and the actions of the student, but performed some communicative gaze behaviors. Steve was later extended in [Rickel et al., 2002], and again in [Lee et al., 2007], to perform additional communicative gaze behaviors.

There are also models of resting gaze, which simulate eye behavior when the eye is not performing any other tasks. For example, the Eyes Alive! system, [Lee et al., 2002] generates stochastic movement based on data collected from an eye tracker system. [Deng et al., 2005], provides another solution by assembling gaze movement stochastically from texture patches, and evaluates his approach directly against an implementation of Eyes Alive!

Additionally, there are attention-based models of gaze – models that perform eye movements based on realistic models of attention and saliency such as described in [Itti, 2005]. These attention models differ from those used in [Rickel & Johnson, 1999] and similar implementations, which modeled attention as a queue of environmental stimuli. Interestingly, while attention based eye movements are likely to be necessary for truly natural gaze behavior, there is evidence that attention can be shifted without actually changing the orientation of the fovea [Jonides, 1981]. One example of a virtual character with attention-based gaze is [Kim et al., 2005], which is extended from an earlier implementation of attention [Hill, 2000]. While this model did not handle social interaction or emotion, it could be extended to do so. Another attention based-model of gaze is shown in [Peters et al., 2005]; where eye movement based on attention is used to show that a virtual agent is interested in a user in order to maintain user interest. [Itti et al., 2003] used a visual neuroscience-based procedural model of eye and head movement in conjunction with a neurobiological model of visual attention to produce an animated head that could realistically attend to salient points in a virtual environment. [Picot et al., 2007] also implemented a saliency-based model of gaze in a virtual agent that was displayed on a screen on a museum tour robot, and successfully interacted with the public.

Models of gaze have also been used to provide semi-autonomous chat or virtual reality avatars with additional believability. For example [Bailenson et al., 2002], linked the head movement of an avatar with the head movement of a user. [Vilhjalmsson & Cassell, 1998], implemented autonomous greeting gaze behaviors, and [Colburn et al., 2000], implemented autonomous gaze based on communicative acts.

While most of these gaze models have not been rigorously evaluated, there are interesting exceptions. The gaze model in [Heylen et al., 2005] is compared to a model of minimal gaze shifts, and one of random gaze shifts. [Deng et al., 2005]'s patch-based model is compared to random movement, and to Eyes Alive! [Lee et al., 2002]. [Fukuyama et al., 2002] implemented a model of gaze based on three parameters: amount of gaze, mean duration of gaze, and direction of gaze aversion. They animated their model using a pair of disembodied virtual eyes, and attempted to manipulate observer's impressions of the agent's personality by changing their gaze parameters. Finally, several of the agents and avatars were evaluated as a whole, but the gaze models were not specifically evaluated [Bickmore & Cassell, 2004], [Bailenson et al., 2002], [Vilhjalmsson & Cassell, 1998], [Colburn et al., 2000].

2.4 Generation of Manner and Style

In addition to the previously described research on implementing models of nonverbal gazing behavior, there has been recent work focused on the manipulation of parameters describing the way in which various types of body movement are performed. This concept is similar to manner, and referred to as "style". It has been described as "variations in the mapping from qualitative states to quantitative observations" [Brand & Hertzmann, 2000].

One of the more influential works on style uses what are called "style machines," combinations of statistical Hidden Markov Models, to allow for easily modifying a style, or learning a style from a motion capture and applying it to another movement [Brand & Hertzmann, 2000]. Another approach to learning style is [Liu et al., 2005]. In this work, values for physics-based style parameters drawn from the biomechanics literature are learned from motion capture using a novel learning method called Nonlinear Inverse Optimization. While this method has demonstrated value in displaying emotional walking behavior, it has not yet been extended to other displays of emotional behavior. Similarly, [Unuma et al., 1995] also generated emotionally expressive walking animations, although they used Fourier transforms to represent the concept of manner, resulting in a technique not applicable to non-periodic movement such as gaze shifts.

In another approach, [Grochow et al., 2004] learned styles using a Scaled Gaussian Process Latent Variable model, and then used the style information to constrain an interactive Inverse Kinematics system. Alternatively, [Rose et al., 1998] interpolated between movements displaying various styles. However, this method does not transfer manner from one movement to another, and thus requires examples of every manner applied to every movement for interpolation purposes.

A parameterized approach to expressing the manner of nonverbal behavior is the EMOTE system [Chi et al., 2000]. In EMOTE, generation of nonverbal behaviors with believable manner is done by using a parameterization based on a choreography-based system for describing movement called Laban Movement Analysis (LMA). EMOTE originally generated hand and arm gestures, but has since been extended to facial expression [Byun & Badler, 2002]. [Zhao & Badler, 2005], further extended EMOTE by learning LMA parameters from either motion capture data or videos of movement. In this approach, professional LMA encoders were used to generate a series of motion capture recordings of the hands and arms. Parameters describing physical movement were then taken from these motion captures, and used train neural networks which output LMA parameters. Finally, EMOTE was used to generate nonverbal behavior for a virtual agent.

Another parameterized representation of manner is the Emotional Transform [Amaya et al., 1996]. The Emotional Transform represents the difference between emotionally acted door-knocking movements and emotionally neutral door-knocking movements, and is used to apply that difference to new door-knocking movements, modifying those into emotionally expressive movements. [Amaya et al., 1996], proposed the Emotional Transform for transferring affective information from one movement to another, but performed no rigorous evaluation of their methods and made no attempt to learn how different emotions are expressed through behavior. [Hsu et al., 2005] developed a method for transferring movement manner using a technique similar to what [Amaya et al., 1996] used for door-knocking movements, although [Hsu et al., 2005] used a linear time-invariant model to represent the style being transferred from one motion to another.

2.5 Previous Work: Encoding Gaze Behavior from Animation

Prior to beginning this work, the feasibility of developing a model of expressive gaze manner driven by an alternative source of data was tested using a preliminary analysis [Lance et al., 2004]. In that work, information available from the psychology literature on nonverbal behavior drove the extraction of physical parameters from gaze shifts that occurred in animated motion feature films, such as Toy Story.

The reasoning behind selecting these movies as a source of data is straightforward: these films represent the gold standard of virtual characters. However, the method used to generate the films, usually key framing performed by skilled animators, takes months to develop. The end result is a set of characters performing believable interactions with several interesting properties: first, the gaze shifts in these interactions are deliberately designed to have intentional communicative value. Second, these gaze shifts are the result of decades of experimentation and learning. In *The Illusion of Life* [Thomas & Johnston, 1981], the authors discuss how the design of the animated eye and the animation of eye behaviors was one of the most difficult problems for early animators to overcome, evolving slowly over decades of work.

In this previous work, a much broader swath of psychological and environmental factors was examined, instead of just looking at how emotional state affected gaze manner. These factors fit into five categories: gaze attraction – whether or not a specific gaze shift was towards a particular target; gaze aversion – whether or not a gaze shift was away from a particular target; emotion related – whether or not a gaze shift was related to the emotional state of the character; task related – whether or not a gaze shift was related to a task the character was performing; speech related – whether or not a gaze shift was related to a speech act the character was performing; and social status – whether or not a gaze shift was related to the relative social status of the interacting characters.

This prior work revealed strong correlations between physical parameters and emotional category. It also showed that the manner of gaze is a highly expressive signal. This is why the focus of the current work is on expressing emotion through gaze manner.

2.6 Conclusion

Despite the wide variety of gaze models discussed here, there are several trends which can be seen running through past implementations of gaze behavior. First, these models focus on when & where the character is supposed to be looking, and not on the manner of the gaze shift. Second, these models, with few exceptions, focus on communicative gaze behaviors, such as interaction control, or gaze for specific tasks, such as monitoring, and not on how gaze reveals emotional state. Third, the behavior generated by these gaze models is usually not formally evaluated through observer testing. The model described in this research differs from these because it is a model of gaze manner focused on expressing emotion, and provides an explicit relationship between gaze behaviors and expressed emotion.

This model also differs from the literature on generating movement style or manner as none of the approaches discussed determine how emotion is attributed by observers to the display of various gaze behaviors. Because this work differs from previous models of gaze, and from previous implementations of style generation, this approach is unique, and is the first model of emotionally expressive gaze manner.

Chapter 3 The Expressive Gaze Model: Gaze Warping Transformation

3.1 EGM Overview

The primary contribution of this research is the Expressive Gaze Model (EGM), which provides the first framework for realizing expressive gaze in interactive virtual characters. This chapter and the next chapter describe the two components of the EGM, the Gaze Warping Transformation (or GWT), which provides expressive head and torso movement during a gaze shift; and the procedural model of eye movement, which provides believable eye movement and integrates that eye movement with the head and torso movement.

There are two primary reasons why the EGM models head and torso movement differently from eye movement. The first is that eye movement by itself is highly stereotypical and contains little emotional content; as pointed out in [Stark et al., 1980]: "[a] subject's intention modifies head movement trajectories greatly, although eye saccades are quite stereotyped." The second is that the eye movement functions on a different time scale and has different constraints than does head or torso movement. As a result, in this work the two are modeled differently, while the relationship between them is constrained.

3.2 Gaze Warping Transformation Overview

The head and torso movement is produced using the Gaze Warping Transformation (GWT), which generates emotionally expressive head and torso movement during gaze shifts [Lance & Marsella, 2007]. The GWT is a lightweight combination of temporal scaling and spatial transformation parameters derived from [Witkin &

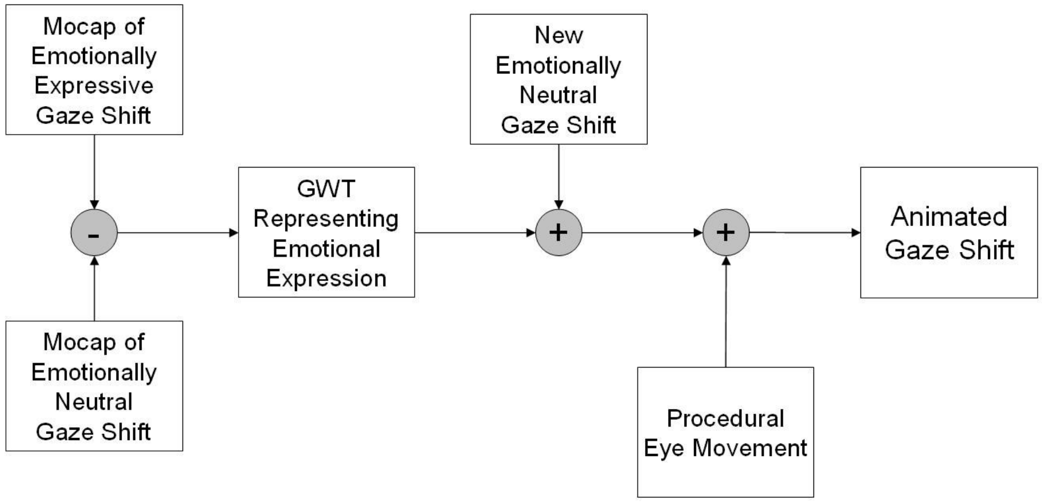

Figure 3-1: EGM Overview

Popovic, 1995] and [Amaya et al., 1996]. At its core, the GWT is a representation of the difference between two gaze shifts. By taking any two gaze shifts, a GWT can be derived from the difference between them, such that if the GWT is applied to one of the gaze shifts, the other gaze shift is produced.

The GWT represents "emotional gaze manner:" the way in which an emotionally expressive gaze shift differs from an emotionally neutral gaze shift towards the same target. To do this, the GWT is derived from the difference between motion capture data of an emotionally neutral and an emotionally expressive gaze shift, both directed from the same initial posture to the same target, as seen in Figure 3-1. This transformation, when applied to an emotionally neutral gaze shift towards a different, arbitrary target, will modify that neutral gaze shift into one which displays the same emotion as the original shift used to produce the GWT. Finally, the procedural eye movement is automatically layered onto the GWT-generated head and torso movement, resulting in an animated gaze shift. By using

Gaze Warping Transformations in this way, gazes are produced that display a desired set of expressive gaze behaviors towards an arbitrary gaze target.

3.3 Motion Capture Data

In order to derive the GWT, the first step is to collect the necessary motion captures of gaze shifts. However, obtaining motion capture data of gaze shifts that reveals emotional state that an observer can identify is a non-trivial problem itself, and numerous unsuccessful data collection attempts were performed before successfully obtaining the motion data used for this research (see Appendix G). Ultimately, sets of behaviors – an example of which is shown in Table 3-1 – were used to collect motion data that displays expressive behaviors. In order to obtain the motion capture, an actor was provided with the set of behavior guidelines, and asked to perform the behaviors.

For each individual data set, two separate data streams were recorded, in addition to video of the session. The first data stream is from a head-mounted eye movement capture rig from Applied Science Laboratories. It records the eye position at 60 Hz using a camera and infrared illuminator mounted on the head rig, and a semi-reflective mirror that reflects the illuminator into the eye and then the eye image back into the camera. While the final gaze model is not based upon the eye tracker data, information about the eye tracker can be found in Appendix E.

The second data stream records the head position and back posture. It is provided by Ascension Flock of Birds (FOB) technology, and uses the movement of sensors through a magnetic field to provide measurements of six degrees of freedom

Table 3-1: Example Behavior Guidelines

Example Behavior Guidelines
Upright Posture Head Turns Upwards Face Is Towards Other Individual
Hunched Forward Posture Head Turns Downwards Face Is Turned Away from Other Individual
Faster Movement Torso Moves Forward Slightly
Slower Movement Torso Moves Backward Slightly

(position and angle) at 60 Hz. Three sensors were attached to each actor: one on the side of the head, one at the base of the neck, and one at the base of the spine. Further information regarding the Flock of Birds system can be found in Appendix D.

3.4 Data Description

The Flock of Birds motion data is collected as a set of time-series data points. Each of the three electromagnetic motion capture sensors records a time stamp, then the position of the sensor in (X, Y, Z) coordinates, followed by the orientation of the sensor as an Euler angle. The eye data is recorded as a time stamp along with a two-dimensional (X, Y) coordinate representing the of the eye's angular position, and pupil dilation. Note that the data was collected in global coordinate frame, as position coordinates were obtained for each value.

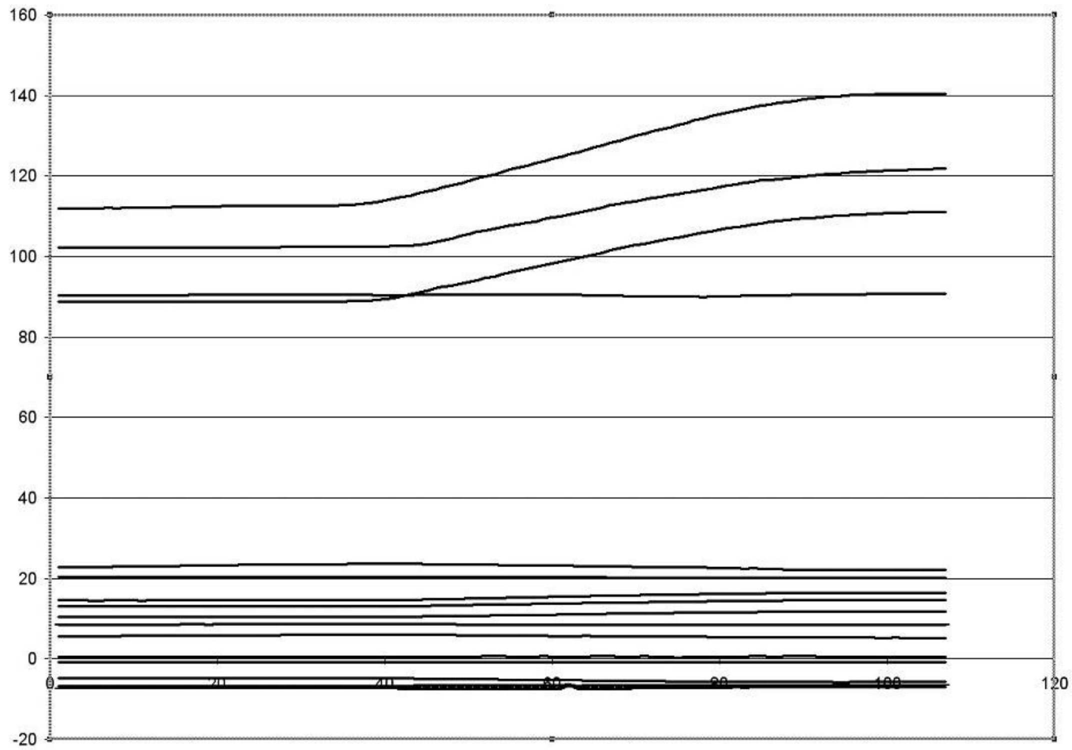

Figure 3-2: Motion Curves for 30 degree Gaze Shift

3.4.1 Motion Curves and Key frames

There are several common representations for this type of motion capture data. Motion captured movements are usually represented as a set of motion curves, where each curve represents the value of a single degree of freedom in the animated body over the number of frames captured in the movement. For example, the motion curves for a 30 degree gaze shift can be seen in Figure 3-2. A common sparse movement representation uses "key frames." The key frames of an animated movement are a subset of the frames for that animation, such that the values of the animation curves for the intermediate frames can be found by interpolating between keyframe values.

3.4.2 Splines

Catmull-Rom splines are used in order to interpolate between the key frames [Foley et al., 1997]. A spline is a parametric function which draws a curve using a set of control points, here modeled as the key frames of the movement. Splines are used for several reasons: The first is that the spline functions as smoothing, cleaning up the noise and outliers in the data. The spline representation also retains some of the time-variability of the data. It could be argued that by converting the data into splines, low level movements important to the display of manner in the movement are lost. However, it is possible to faithfully recreate the original motion to a high degree of accuracy using splines, assuming a sufficient number of control points.

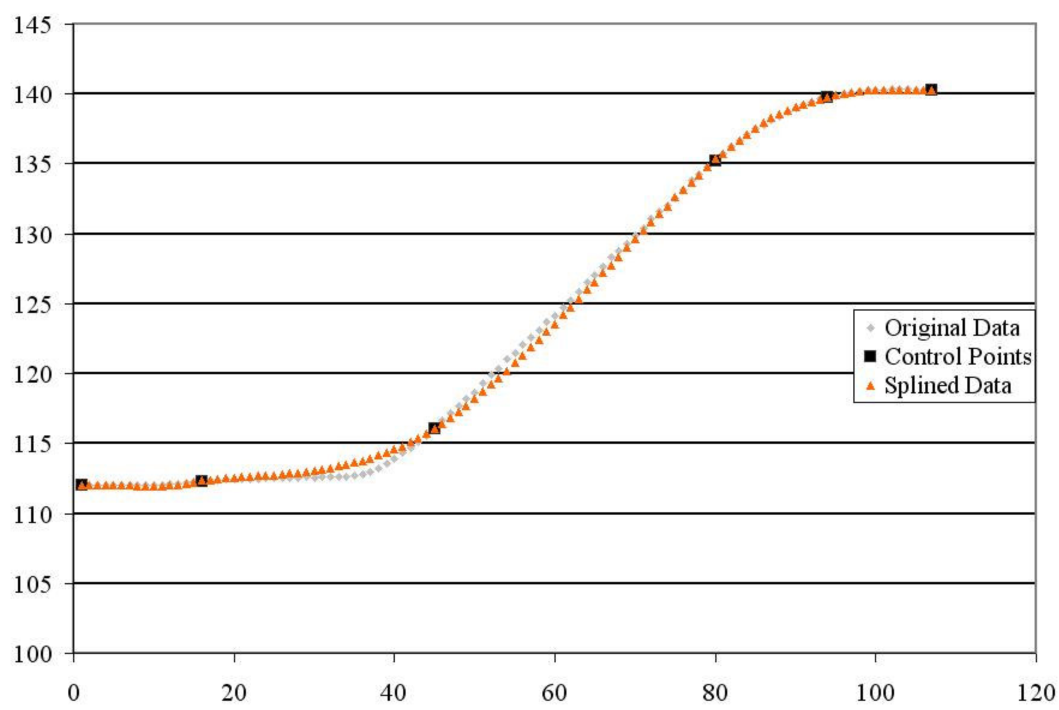

Figure 3-3: Original Motion Data, Spline Data, and Key frames

For example, see Figure 3-3, which shows the movement curve that represents the horizontal rotation of the head, taken from original motion capture data; the key frames distilled from that movement; and the cubic interpolated spline that connects them.

Currently, six Catmull-Rom control points are used as the key frames for each gaze shift. While six points has shown adequate performance so far, modeling more complex gaze behavior may require either increasing the number of control points, or segmenting the complex behavior into simpler gaze shifts. If necessary, larger numbers of spline control points could be used, up to the full set of collected data.

3.4.3 Segmentation

To ease processing, the sets of captured data were segmented into individual gaze shifts; which, in this work, are defined as at most one major head movement, one major torso movement, and one major eye movement. The data was divided into gaze shifts based on the points when the head is stationary in the direction with largest angular displacement, as the head performs the easiest to distinguish and largest amplitude movements. The segmentation points are recorded in the motion capture data during the data collection session by having an individual observe the performing actor and place markers into the motion capture data at the appropriate times.

3.5 Finding the GWT

A GWT is found by obtaining two motion captures of gaze shifts directed from the same start point to the same target – one emotionally expressive, the other emotionally neutral – and finding a set of point to point warping parameters (based on Motion Warping [Witkin & Popovic, 1995]) that would convert the key frames of the motion curve representing each degree of freedom in the emotionally neutral animation into the key frames of the motion curve for the corresponding degree of freedom in the emotionally expressive movement.

3.5.1 Aligning Key frames

As the GWT is a set of point-to-point transformations, the key frames from each individual gaze shift need to align. If they do not, the result is that a transformation derived from a specific location in one gaze shift is applied to a nearby, but not corresponding location on another gaze shift. These misapplications can lead to visible artifacts in the animations. Specifically, the character can "pop" from one position to another, without moving through the intervening space.

In order to align the key frames, all gaze shifts are aligned to a "stereotypical gaze shift," using an alignment algorithm derived from that described in [Amaya et al., 1996]. This algorithm aligns the curves of two animations or motion captures based on the ratio of movement which has occurred by a specific time to that which occurs throughout the entire curve. The values used for alignment are found using:

$$\hat{f}(t) = \frac{\sum_{\tau=0}^{t} \left|\mathbf{v}(\tau)\right|}{\sum_{\tau=0}^{t_{end}} \left|\mathbf{v}(\tau)\right|} \tag{1}$$

where $\mathbf{v}(t)$ is the three dimensional velocity vector of the head. The movement of the head, which is generally of higher amplitude than that of the torso during a gaze shift, is used as an approximation for movement of the entire body. For example, to align two movement curves: the first of which has 20% of its head movement occur by frame 50, while the other has 20% of its movement occur by frame 75, then those two frames are first aligned. By repeating this process for every frame in both curves, a mapping between the curves which aligns them accurately is found. The key frames for each gaze shift are found by aligning that shift with the "stereotypical" gaze shift, ensuring that transformations are then applied to corresponding locations.

The "stereotypical" gaze shift was found by averaging the head movement of thirty-three emotionally neutral gaze shifts. These gaze shifts were all scaled to the same length of time in frames, and then transformed to begin at the same initial

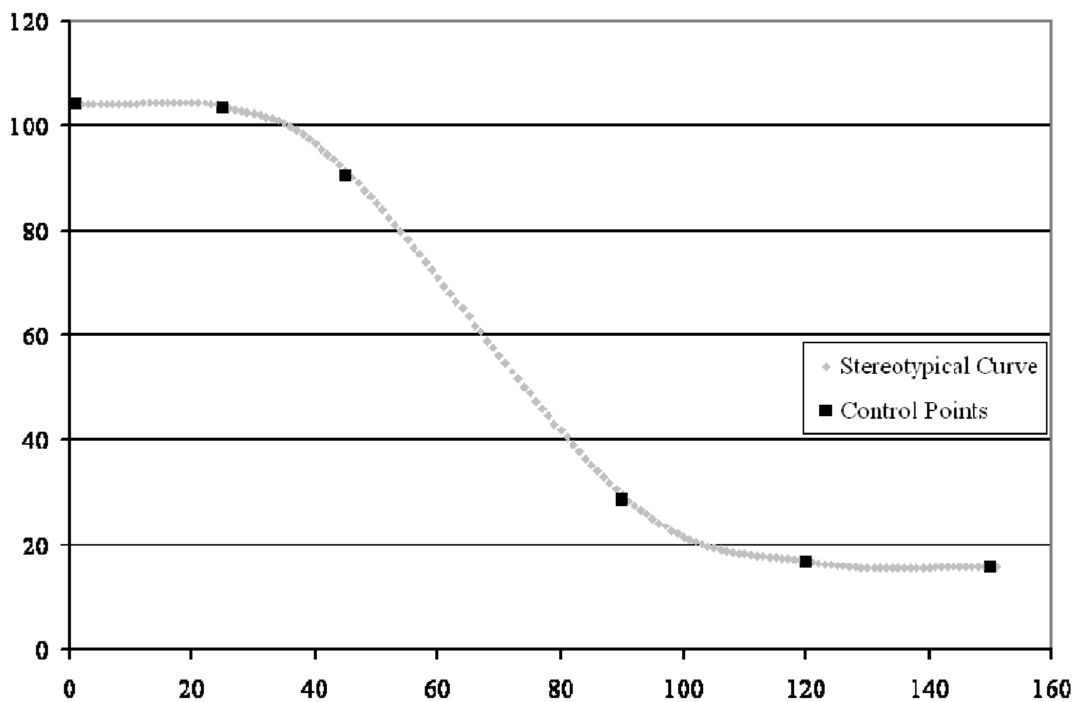

Figure 3-4: Stereotypical Curve with Control Points

Table 3-2: Stereotypical Curve Control Point Movement Ratios

0
0.019772
0.175039
0.830231
0.982697
1

point. Then, the values for each motion curve were averaged across the thirty-three gaze shifts, leaving one "stereotypical" gaze shift. Keyframes were then placed on this stereotypical shift by hand. Figure 3-4 shows the averaged, stereotypical curve and the hand-placed keyframes, while Table 3-2 contains the movement ratios that the keyframes occur at. In order to place keyframes on a new gaze shift, the times in that gaze shift that correspond to the movement ratios in Table 3-2 are found, and those frames are selected as the keyframes.

3.5.2 GWT Parameterization

The GWT is derived from the difference between the key frames of two animation curves, $u(t)$ and $v(t)$, respectively defined as the sets of (frame, value) pairs (ut_i, u_i) and (vt_i, v_i). The GWT is then used to transform the key frames of an animation curve $x(t)$ defined as a set of (frame, value) pairs (t_i, x_i); to those of a new motion $x'(t')$ defined as the set of pairs (t_i', x_i') [Lance & Marsella, 2007]. The GWT is represented as an $m * n$ set of (c_i, b_i) pairs, where m is the number of degrees of freedom in the animated body and n is the number of key frames in the animation. Each (c_i, b_i) pair then represents the difference between the key frames (ut_i, u_i) and (vt_i, v_i), and transforms (t_i, x_i) into (t_i', x_i').

In each pair of the GWT, c_i is a time scaling factor which represents the temporal difference between two key frames, while b_i is a spatial offset parameter that represents the difference between the spatial values of the two key frames. c_i is calculated from the key frames of u and v by the formula:

$$c_i = \frac{ut_i - ut_{i-1}}{vt_i - vt_{i-1}} \tag{2}$$

as shown in Figure 3-5. It then transforms the key frames t_i of x, into the t_i' of x':

$$t_i' = t_{i-1}' + c_i(t_i - t_{i-1}) \tag{3}$$

The spatial offset parameter b_i is calculated from the spatial values of u and v:

$$b_i = u_i - v_i \tag{4}$$

as shown in Figure 3-6. It then transforms x into x' using the formula:

$$x_i' = x_i + b_i \tag{5}$$

As the GWT is a point wise transformation of the key frames, these operations are then repeated for every keyframe of every motion curve of the gaze shift, resulting in the full transformation.

3.6 Exemplifying the GWT

In this section, a brief example of deriving and applying the GWT is provided. First, a derivation of the GWT will be shown using the following two sets of example key frames u and v:

$$u = \begin{bmatrix} ut_1, u_{11} & ut_2, u_{12} \\ ut_1, u_{21} & ut_2, u_{22} \end{bmatrix} \tag{6}$$

$$v = \begin{bmatrix} vt_1, v_{11} & vt_2, v_{12} \\ vt_1, v_{21} & vt_2, v_{22} \end{bmatrix} \tag{7}$$

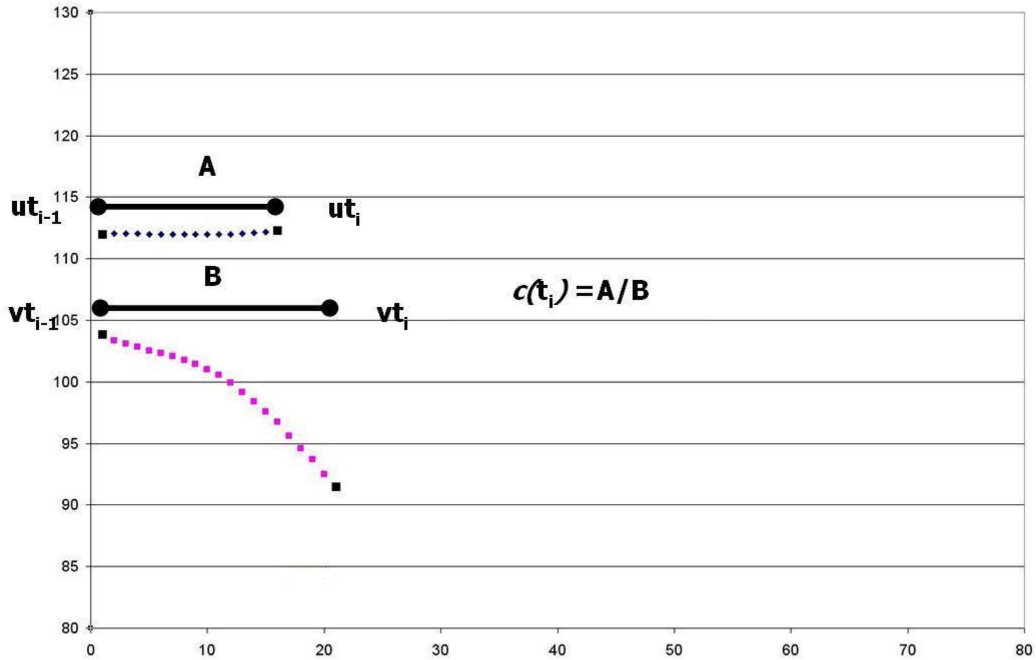

Figure 3-5: Calculating Time Scaling Parameter *c*

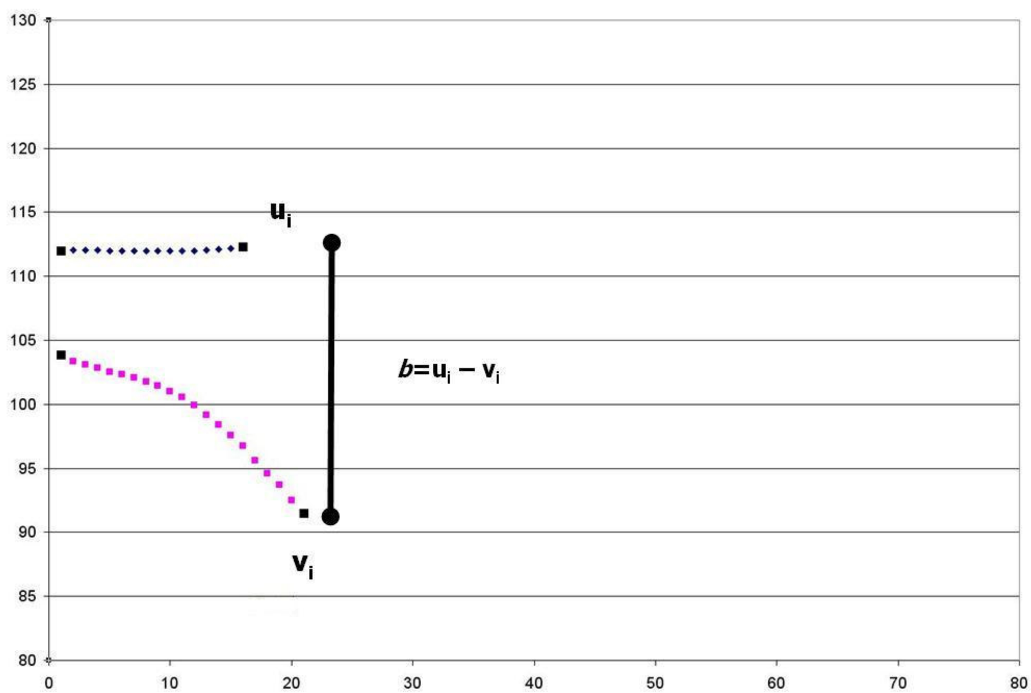

Figure 3-6: Calculating Spatial Transformation Parameter *b*

where u is an emotionally expressive gaze shift and v is an emotionally neutral gaze shift directed towards the same target. Then the GWT g between u and v is derived:

$$g = \begin{bmatrix} \frac{ut_1}{vt_1}, u_{11} - v_{11} & \frac{ut_2 - ut_1}{vt_2 - vt_1}, u_{12} - v_{12} \\ \frac{ut_1}{vt_1}, u_{21} - v_{21} & \frac{ut_2 - ut_1}{vt_2 - vt_1}, u_{22} - v_{22} \end{bmatrix} \tag{8}$$

Once the GWT is derived it can be used to generate a gaze shift towards a new target that displays the emotional behaviors that occur in u but not in v. As an example, by applying the following GWT g:

$$g = \begin{bmatrix} c_1, b_{11} & c_2, b_{12} \\ c_1, b_{21} & c_2, b_{22} \end{bmatrix} \tag{9}$$

to an emotionally neutral gaze shift K:

$$K = \begin{bmatrix} t_1, x_{11} & t_2, x_{12} \\ t_1, x_{21} & t_2, x_{22} \end{bmatrix} \tag{10}$$

a new emotionally expressive gaze shift can be generated. The appropriate transformations are applied to each animation curve in K at each keyframe, generating the key frames for the new gaze shift K', which is directed at the desired target and displays the desired behavior.

$$K' = \begin{bmatrix} t_1 * c_1, x_{11} + b_{11} & (t_2 - t_1) * c_2, x_{12} + b_{12} \\ t_1 * c_1, x_{21} + b_{21} & (t_2 - t_1) * c_2, x_{22} + b_{22} \end{bmatrix} \tag{11}$$

Finally, the key frames for the gaze are interpolated into motion curves.

3.6.1 Inverting Gaze Warping Transformations

When applying GWTs it must be noted that they often possess directionality. For example, GWTs obtained from emotional and neutral gazes turning to the left may not be applicable to gaze shifts that turn to the right. In order to deal with this, two types of inversion are utilized: directional and temporal. These inversions allow the generation of broader patterns of gaze behavior with smaller numbers of Gaze Warping Transformations. For example, instead of having to capture left and right versions of a GWT, directional and temporal inversions can be used to simulate the results. Consider the following two-by-two GWT g that applies vertical and horizontal changes to a body:

$$g = \begin{bmatrix} c_1, b_{11} & c_2, b_{12} \\ c_1, b_{21} & c_2, b_{22} \end{bmatrix} \tag{12}$$

In this example GWT, b_{11} and b_{12} modify horizontal movement and b_{21} and b_{22} modify vertical movement, while c_1 provides the timing of the first key frame and c_2 provides the timing of the second keyframe. Directional inversion consists of sign-inverting the spatial offset parameters in the dimension desired. To perform a horizontal directional inversion, g is modified to:

$$g = \begin{bmatrix} c_1, -b_{11} & c_2, -b_{12} \\ c_1, b_{21} & c_2, b_{22} \end{bmatrix} \tag{13}$$

Similarly, to perform a vertical directional inversion, g is modified to:

$$g = \begin{bmatrix} c_1, b_{11} & c_2, b_{12} \\ c_1, -b_{21} & c_2, -b_{22} \end{bmatrix} \tag{14}$$

In order to perform a temporal inversion, the frame timings of the GWT are reversed in order. Thus, the result of a temporal inversion of g is:

$$g = \begin{bmatrix} c_2, b_{11} & c_1, b_{12} \\ c_2, b_{21} & c_1, b_{22} \end{bmatrix}. \tag{15}$$

3.6.2 Constraining the Animation

As the GWT is based on Motion Warping, a technique of simple geometric transformations, the animations generated through applying the GWT may contain artifacts such as body parts moving outside the physical limits of an actual human body [Witkin & Popovic, 1995]. This is a common problem seen in other manner manipulation techniques as well [Hsu et al., 2005], [Rose et al., 1998]. In order to remove this problem of motion outside physical limits, the animated body is constrained to stay within its physical limits.

For this, an inverse kinematics (IK) system was implemented using nonlinear optimization [Zhao & Badler, 1994]. This keeps the head of the animated body firmly attached to its torso. Since the specific problem was that the head came detached from the torso, the IK system added in a neck joint between the head and the torso, with two bones: one running from the location of the shoulder motion tracker to the neck, and one running from the neck to the location of the head tracker. Information on the IK system can be found in Appendix F.

Figure 3-7: Animation Before and After IK System

Table 3-3: List of Emotionally Neutral Gaze Shift Angles

Right	Left	Up	Down
-9°	9°	13°	-10°
-21°	21°	20°	-23°
-35°	35°	30°	-34°
-54°	54°	50°	-43°
-62°	62°		

The results of the IK system can be seen in Figure 3-7, which shows an image from the same animation before and after the IK system was implemented. The model in this animation is the one used in the evaluation of the GWT described at the end of this chapter. This IK solution performs very well for the small number of sensors used to obtain the motion capture data.

3.6.3 Using the GWT to Generate Neutral Gaze Shifts

In order to generate emotionally expressive gaze shifts containing head or torso movement to an arbitrary target, GWTs transform emotionally neutral gaze shifts directed towards that target into emotionally expressive gaze shifts. Therefore, the neutral gaze shift to transform using the GWT must first be obtained. However, GWTs can also generate these neutral gaze shifts as well. To do this, angular GWTs are found by determining the difference between a stationary body and one performing a gaze shift at a known target.

This set of angular GWTs (shown in Table 3-3) is comprised of two subsets: one which contains vertical (pitch) rotations only, and one which contains horizontal (yaw) rotations only. In order to perform a gaze shift from an arbitrary location to an arbitrary location, the horizontal and vertical angular differences between the start and end positions are found. Then, the horizontal and vertical GWTs which perform a rotational change closest to the desired rotational change are scaled by the ratio between the desired angle α and the closest stored angle β using scaling factor s:

$$s = \frac{\alpha}{\beta} \tag{16}$$

Then, these two GWTs are combined by summing the movement curve values at the key frames. This simple combination works because the horizontal and vertical GWTs have very little overlap in the movement curves that they affect.

Finally, the resulting angular GWT is applied to a set of key frames that represents a stationary position held by the character. The resulting GWTs describing these neutral gaze shifts can be seen in Appendix J. This procedure maintains coherency with the model of emotionally expressive gaze; although the emotionally neutral gaze shifts to arbitrary targets could be generated in any fashion: such as motion capture, procedural generation, or keyframe hand animation.

3.7 Benefits of the GWT

There are a number of benefits to this representation of the Gaze Warping Transformation. The primary two are Behavior Layering and Compositionality.

3.7.1 Behavior Layering

The GWT allows the representation of emotionally expressive behaviors by finding the transformation between an emotionally expressive gaze shift and an emotionally neutral gaze shift that both start in the same position, and end gazing at the same target. These emotionally expressive gaze behaviors can then be used to transform gaze shifts to arbitrary targets, layering the desired emotionally expressive behavior on top of the new gaze shift. This allows for the generation of gaze shifts expressing desired behavior to arbitrary targets while requiring motion capture of only the gaze shift expressing the desired behavior.

3.7.2 Compositionality

If two (or more) GWTs affect non-overlapping motion curves, both GWTs can be layered onto a single gaze shift. The resulting gaze shift then displays both expressive behaviors. Both compositionality and behavior layering are demonstrated through the generation of emotionally neutral gaze shifts using GWTs. In addition, this composition of physical gaze behaviors allows exploration of the relationship between composing physical gaze behaviors and the composition of emotion, described further in Chapter 5.

3.7.3 Additional Advantages

In addition to these two primary advantages, the GWT is also very lightweight, allowing for a very rapid application to new gaze shifts. Further, it is not dependent upon anatomy, allowing for additional joints and degrees of freedom to be added to the GWT representation as needed. Finally, the GWT is not dependent on curve representation, allowing it to be determined from, or applied to different sources of motion data, such as motion capture, keyframe animation, or even procedural animation, as long as the key frames or motion curves can be obtained from the animation system.

3.8 Evaluating the Benefits of the GWT

Before developing a model of eye movement, a preliminary evaluation of the GWT was performed [Lance & Marsella, 2007]. The purpose of this evaluation was to test the behavior layering and compositionality of the GWT. The procedure to this evaluation was as follows: first, recordings of head, eye, and torso movement were made of actors performing emotionally expressive and emotionally neutral gaze shifts. Then, the GWT parameters were determined from the difference between the emotionally expressive and emotionally neutral gaze shifts. GWTs from multiple emotionally expressive gaze shifts were then composed and layered onto emotionally neutral gaze shifts directed towards different targets from the original expressive gaze shifts, transferring the physical properties of the emotional gazes to the neutral gaze. Finally, the animations of these generated gaze shifts were displayed to subjects who rated the animations based on the emotion expressed. As this evaluation was focused entirely on the GWT, it did not address the problem of eye movement.

3.8.1 Emotion Model

The model of emotion used for this evaluation was derived from the PAD model of emotion, described in [Mehrabian, 1981]. The PAD model is a dimensional model of emotion that views the set of possible emotions as a space, which can be described with three emotional dimensions. The first dimension is pleasure/displeasure. The second is arousal/nonarousal. Mehrabian defines arousal as a combination of alertness and activity.

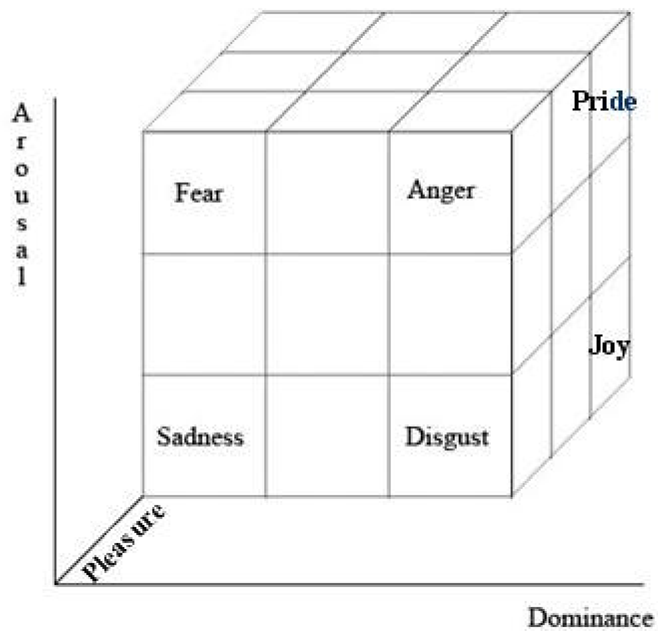

Figure 3-8: PAD Dimensional Model of Emotion

Thus, a highly aroused individual is both alert and physically active, while a non-aroused individual would be neither. The third emotional dimension is dominance/submissiveness.

The intuitive categories of emotion, such as anger, sadness, fear, or happiness, can be represented in this model by sub regions in the space defined by the emotional dimensions. For example, anger can be defined as negative valence, high arousal, and high dominance, while fear can be defined as negative valence, high arousal, and low dominance, and sadness can occupies a region where valence is negative, and arousal and dominance are both low. A visual depiction of the emotional dimensions and one possible division into categories can be seen in Figure 3-8.

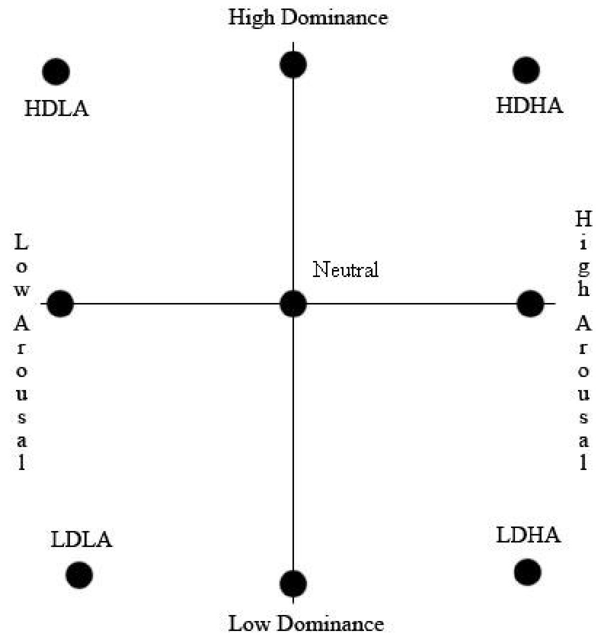

Figure 3-9: Emotional Dimensions and Captured Regions

There are many alternative emotional models that could have been chosen. For example, one alternative would be an appraisal model, where emotional state is defined in terms of a set of appraisal variables, such as in [Gratch & Marsella, 2004]. However, the PAD dimensional model is capable of describing emotional categories and is composed of a manageable number of dimensions, each of which have a background of research describing nonverbal behaviors associated with them [Paterson et al., 2001], [Carney, 2005], [Kappas et al., 1994].

This preliminary evaluation only utilized a subset of the PAD dimensional model of emotion – specifically the Arousal and Dominance dimensions. This is because Arousal and Dominance are more closely related to gaze than pleasure [Kleinke, 1986]. The resulting emotional space can be seen in Figure 3-9.

The data for this preliminary evaluation was collected by motion capture from gaze shifts performed by an actor who was provided with the set of behavior guidelines shown in Table 3-4. The basis of these guidelines are the findings that coders will rate an individual with upright head and posture as more dominant than one slouching forwards [Carney, 2005], [Mignault & Chaudhury, 2003], as well as results showing that velocity is clearly identified with arousal (for example in gesture [Paterson et al., 2001]). The focus for these behavior guidelines was on those physical properties reliably decoded as displaying dominance and arousal by observers, as opposed to how dominance and arousal are actually encoded in behavior.

3.8.2 Motion Capture Collection

Each dimension was divided into discrete high and low values, providing nine distinct regions of the emotional space: Neutral Dominance and High Arousal (HA), Neutral Dominance and Low Arousal (LA), Neutral Arousal and High Dominance (HD), Neutral Arousal and Low Dominance (LD), High Arousal and High Dominance (HAHD), High Arousal and Low Dominance (HALD), Low Arousal and High Dominance (LAHD), Low Arousal and Low Dominance (LALD), and the emotionally neutral origin, as shown in Figure 3-9.

Behavior guidelines (shown in Table 3-4) for each of these emotional regions were determined from the nonverbal behavior literature. Using these guidelines, two sets of motion capture data were collected. For the first set, an actor was provided with the guidelines and demonstrated the behaviors while performing four to six gaze shifts from a target 90 degrees to the left side of the actor to another target

Table 3-4: Predicted Physical Behaviors

Emotional Dimension	Behavior Guidelines
High Dominance (HD)	Upright Posture Head Turns Upwards Face Is Towards Other Individual
Low Dominance (LD)	Hunched Forward Posture Head Turns Downwards Face Is Turned Away from Other Individual
High Arousal (HA)	Faster Movement Increased Blink Rate Torso Moves Forward Slightly
Low Arousal (LA)	Slower Movement Decreased Blink Rate Torso Moves Backward Slightly

straight ahead of the actor. The actor then performed this same gaze shift while displaying no emotion, and not performing the above behaviors. The GWTs are derived from this set. The second set of data consists of the actor performing the combined behaviors for HAHD, HALD, LAHD, and LALD while shifting gaze from a target 90 degrees to the actor's left to a target to their front. This set is used for evaluation, in which composed GWTs for HAHD, HALD, LAHD, and LALD were compared to the corresponding motion capture data.

3.8.3 Initial Data Evaluation

After capturing the gaze data, it was evaluated in order to avoid developing a model of gaze manner based on incorrect expectations about the expressivity of the gaze behaviors. It was possible that the guidelines as to how emotional dimensions are decoded from gaze behaviors were incorrect, or that the actor's performance was lacking, leading to an unclear emotional display or even the incorrect emotion being displayed. For this data evaluation, animations generated directly from the first set of motion captures, and portraying the emotional states LD, HD, HA, and LA, were displayed in pairs to eleven coders, who rated each animation individually on 5-point scales of dominance and arousal. Each coder saw each animation three times.

Two analyses of variance (ANOVAs) compared the ratings of animations along the emotion scales. Ratings of LD animations on the dominance scale (M = 2.515) were significantly different from ratings of HD animations (M = 3.727), and from ratings of animations neutral on the dominance scale (M = 3.348, $F(2, 131) = 12.1474$, $p < .01$), although HD animations were not significantly different from dominance-neutral animations.

Similarly, ratings of HA animations on the arousal scale (M = 3.909) were significantly different from ratings of LA animations (M = 2.727) and from animations neutral on the arousal scale (M = 2.803, $F(2, 131) = 12.2311$, $p < .01$), though LA and arousal-neutral animations did not significantly differ.

Because coders significantly differentiated between low and high values for both dominance and arousal, and the neutral animations for each scale fell between low and high, the GWTs were drawn from these animations.

3.8.4 Combining Gaze Warping Transformations

GWTs were combined by selecting entire motion curves that significantly differed across emotional dimensions from the component GWTs. While this combination process was performed for this evaluation, it was not utilized for later studies. However, it did lead to the development of the more low-level behavior based system used in the empirical study described in Chapter 5.

Table 3-5: Some Significant Emotional and Movement Relationships

Movement Dimension	Emotional Dimension	Observed Change
Speed	Arousal	Low Arousal Animations are 80% slower than High Arousal Animations
Head Rotation – Pitch	Dominance	Low Dominance Head Pitch is 25 degrees lower than High Dominance
Torso Movement - Front/Back	Arousal	The torso moves forwards 1.5 inches more in High Arousal than Low Arousal Animations
Torso Movement – Vertical	Dominance	The torso moves down 1 inch more in Low Dominance than High Dominance Animations

To determine which motion curves significantly differed across emotional dimensions, a series of ANOVAs were used to compare individual Gaze Warping Transformation values across different emotional dimension values. Twelve low arousal GWTs were compared to twelve high arousal GWTs (n = 24), and twelve low dominance GWTs to fourteen high dominance GWTs (n = 26), running one ANOVA for each element in the GWTs. A subset of the results, which demonstrate the behavior guidelines described in Table 3-4, can be seen in Table 3-5. For example, the guidelines called for changes in speed and forwards/backwards position of the torso to show arousal. Dominance was also significantly related to head pitch and torso vertical position. The warping parameters thus provided specific values for the abstract, general guidelines expressed in Table 3-4.

In order to combine two GWTs, the resulting GWT was made by selecting rows (i.e. motion curves) that differed most significantly across that emotional dimension. For example, to combine a High Arousal GWT with a High Dominance GWT, the rows in the High Arousal GWT that significantly differ from rows in a

Low Arousal GWT would be combined with the rows from the High Dominance GWT that significantly differed from the rows in a Low Dominance GWT.

3.8.5 Producing Emotionally Expressive Animations

Because the goal of this evaluation was to test both the behavior layering and compositionality properties of the GWT, the GWTs for the individual emotional dimensions were combined to generate animations of HDHA, HDLA, LDHA, and LDLA; for example by combining HD & HA instead of using the GWT obtained from the HAHD capture. These combined GWTs then transformed three emotionally neutral gaze shifts that all started with the actor gazing straight ahead. The first emotionally neutral "gaze shift" was a stationary gaze straight ahead, the second turned 20° to the actor's left, and the last turned 45° to the actor's left. This resulted in manner parameters being taken from attraction gazes, looking towards a target directly ahead of the actor; combined together, and then applied to aversion gazes that looked away from a target ahead of the actor. An example transformation of the Head Rotation – Pitch movement curve can be seen in Figure 3-10.

Finally, the new emotionally expressive gaze shifts were animated on a very simple model in Maya (Figure 3-11) by reformatting the motion curves into a BioVision Hierarchy (BVH) motion capture file (Appendix A), importing this file into Maya, and using it to drive a virtual body. This virtual character is a simplified humanoid shape, with no arms and a rudimentary face that is incapable of facial expression. The simplicity of the body is to ablate nonverbal signals sent from unused body components, such as arms that do not move, or an unexpressive mouth.

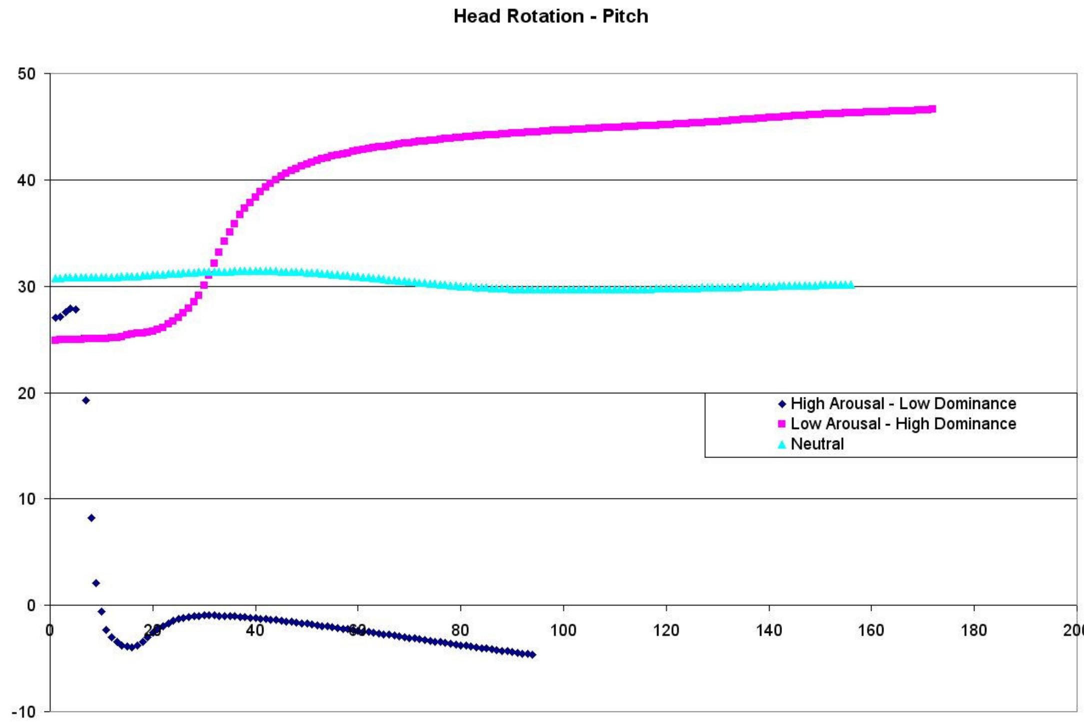

Figure 3-10: GWT Transforming Neutral to HALD and LAHD

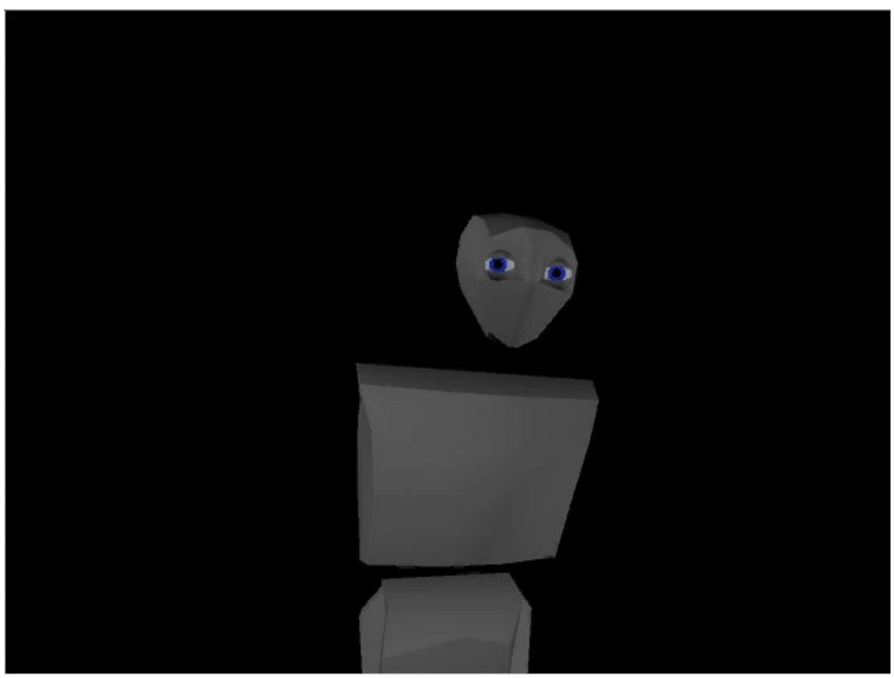

Figure 3-11: Animated Body

3.8.6 Evaluation and Results

The evaluation determined if the emotional signals in the GWT generated animations for HDHA, HDLA, LDHA, and LDLA were coming through as strongly as the emotional signals in motion-captured animations of the same emotional states. To do this, the animations and a questionnaire were provided (an example of which can be found in Appendix B) to 21 subjects. Ten subjects saw the set of twelve GWT generated animations, while eleven coders saw the set of four motion-captured animations. Animations were arranged according to a Latin Square, and displayed to subjects in pairs, differing along either arousal or dominance, but not both. The subjects selected the animation that showed higher arousal and the animation that showed a more dominant character. Then, they rated the arousal and dominance of each animation individually on five-point scales. Each subject saw each animation twice, but rated it only once on dominance, and once on arousal.

The result of this evaluation showed that subjects significantly distinguished between low and high arousal, and between low and high dominance, for both the generated and motion captured animations, as shown by a Chi squared test. The ability to distinguish arousal was similar for both the generated and captured animations (see Table 3-6). When asked to select the more highly aroused animation, the subjects selected the generated animation intended to display high arousal 85% of the time, while the percentage was 86% for the captured animations.

The results for dominance can be seen in Table 3-7. Unlike arousal, the recognition for dominance, while still significant, was lower for the generated animations (66%) than for the captured animations (90%).

Table 3-6: Preliminary GWT Evaluation Results - Arousal

	Arousal	
Statistic	**Generated Animations**	**Captured Animations**
Number of Comparisons	60	22
Comparison Recognition	85%	86%
Comparison *p*	<.01	<.01
Number of Ratings	120	44
Low Arousal Mean Rating	3.000	2.80
High Arousal Mean Rating	3.817	3.70
F	9.045	15.2821
ANOVA *p*	<.05	<.01

A within-subject Multivariate ANOVA showed that ratings on the scales were also significantly ($p < .05$) different for low and high arousal animations. However, the scale ratings were not significantly different for low and high dominance in the animations generated with the GWT, although they were for the motion-captured animations. The interaction effects were also not significant.

During debrief, subjects explained that the character appeared to be looking at objects instead of expressing emotion. These concerns were addressed by the inclusion of an eye model, discussed in the next chapter.

Table 3-7: Preliminary GWT Evaluation Results - Dominance

	Dominance	
Statistic	**Generated Animations**	**Captured Animations**
Number of Comparisons	60	22
Comparison Recognition	66%	90%
Comparison *p*	<.01	<.01
Number of Ratings	120	44
Low Dominance Mean Rating	3.000	2.55
High Dominance Mean Rating	3.333	3.70
F	2.250	30.9729
ANOVA *p*	.168	<.01

3.9 Conclusion

The evaluation results showed that the GWT is capable of capturing the manner of emotionally expressive gaze shifts. This behavior can then be composed, and then layered onto different emotionally neutral gaze shifts, from which the subject can recognize the original emotional signal. It also revealed that there was room for improvement, specifically with regards to the signaling of dominance. The dominance animations that obtained the lowest recognition were those where the movement was quick and the animation did not end facing straight ahead.

Chapter 4 The Expressive Gaze Model: Eye Movement

4.1 Overview

In addition to the GWT, which describes movement of the head and torso during gaze shifts, the expressive gaze model also contains an integrated procedural model of eye movement, based primarily on the visual neuroscience literature, and described in [Lance & Marsella, 2008a].

Originally, the intent was to use an eye tracker to collect eye data (Appendix E), and base the model of eye movement off of that data. However, the head-mounted eye tracker lost track of the eye in many common situations. For example, it lost track when the eye moved too far away from looking straight ahead, or if the head moved too quickly. Further, the collected data matched with the stereotypical eye movements described in the visual neuroscience literature, which used more intrusive but more accurate eye tracking technology, such as electromagnetic sensors mounted on contact lenses. Therefore, the model of eye movement uses these stereotypical movements, instead of collected eye movement data.

4.2 Types of Eye Movement

In [Leigh & Zee, 2006]'s overview of visual neuroscience, the authors identify several different functional classes of eye movement. Those which are relevant to this work are the vestibular and optokinetic, both of which maintain visual fixation during head movement; and saccades, which are rapid and highly stereotyped eye movements to a specific target. In addition, [Leigh & Zee, 2006] discuss the combination of head and eye movement, through the existence of eye-head saccades.

Thus, this model implements vestibulo-ocular reflex (VOR) movement, saccades, and combined eye-head saccades. In addition, VOR with head movement is differentiated from VOR with head and torso movement, and the model similarly differentiates between combined eye-head saccades and eye-head-torso saccades. Table 4-1 lists the movements implemented in the procedural model of gaze.

4.2.1 Eye Movement Representations – Saccade

Figures 4-1 through 4-4 show how eye movements are represented for each of the different types of gaze shift. In each figure, the Gaze Angle curve represents the target of the entire gaze, combining eye and head orientation. The Eye Angle curve represents the angle of the eyes within their orbit, and the Head Angle curve represents the angle of the head relative to its initial position.

Figure 4-1 shows the motion curves for a stereotypical saccade in one dimension, and an animated figure showing the beginning and ending of the saccade. The saccade is a very rapid, highly-stereotyped eye movement which rotates the eye from its initial position directly to the target. The size, speed, and duration of saccadic movements are closely related. As the amplitude of a saccade increases, so does its velocity and duration. These relationships are called the main sequence relationships, and define ranges for standard saccades [Stark et al., 1980].

Table 4-1: Gaze Shifts Implemented in Model

Gaze Type
Eye-Only Shift
Eye-Head Shift
Eye-Head-Body Shift
Head-Only Movement
Head-Body Movement

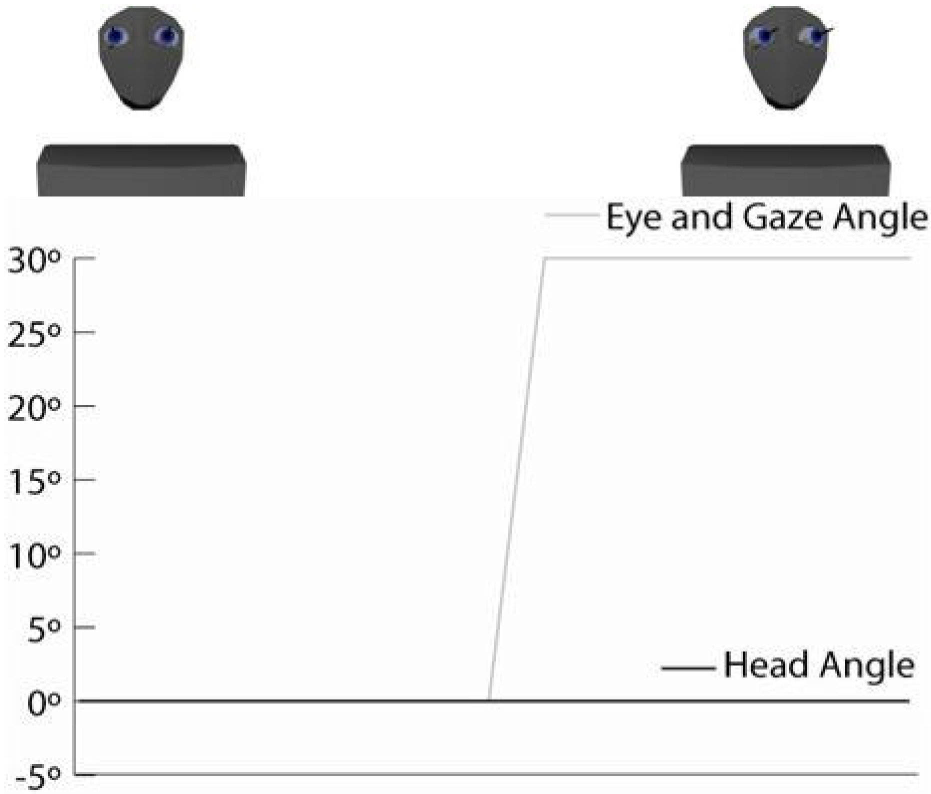

Figure 4-1: Stereotypical Saccade

Eye movement outside these ranges is either non-saccadic behavior, or an abnormal saccade, often symptomatic of pathology [Leigh & Zee, 2006], [Zee, 1976].

The representation of saccadic movement is that of a rotation to the desired target, with additional considerations: the main sequence relationship between amplitude and duration is approximated as a linear relation between the amplitude of the saccade and the number of frames of animation the saccade takes to execute. For each ten degrees of amplitude, one intermediate frame is added. Then, linear interpolation between the start and end positions determines intermediate orientation of the eye across these animation frames. The velocity is thus not directly controlled, but implicitly determined by the amplitude and duration. Saccade amplitude is also limited to +-45º. While the mechanical limits of human eye movement are closer to +-55º, there is evidence showing that there are neural limits that saturate eye movement at +-45º [Guitton & Volle, 1987].

In order to generate a saccadic gaze shift that does not have concurrent head and torso movement, a stationary posture lasting for the desired number of frames of animation is generated by replicating the last known posture of the animated character, and adding slight perturbations to avoid the robotic appearance of utter stillness. The stereotypical saccade representation then determines the location of the eyes at every frame of the animation, and the resulting movement drives the animated character.

4.2.2 Eye Movement Representations – VOR

Figure 4-2 shows the motion curve for a head movement with VOR. It also shows an animated character demonstrating the VOR movement. Through the vestibulo-ocular reflex, the eyes rotate within their orbit so that the gaze maintains the same target while the head moves. Since the VOR is a non-saccadic movement, it is not subject to the main sequence relationship, allowing slower eye rotation to match the head rotation. However, movement is still limited to +-45º.

The VOR eye movement is implemented by first applying the desired GWT to an emotionally neutral gaze shift to generate an emotionally expressive movement. Then the eye orientation is determined by simply rotating the eyes opposite to the head rotation, so that the eyes maintain the same gaze target.

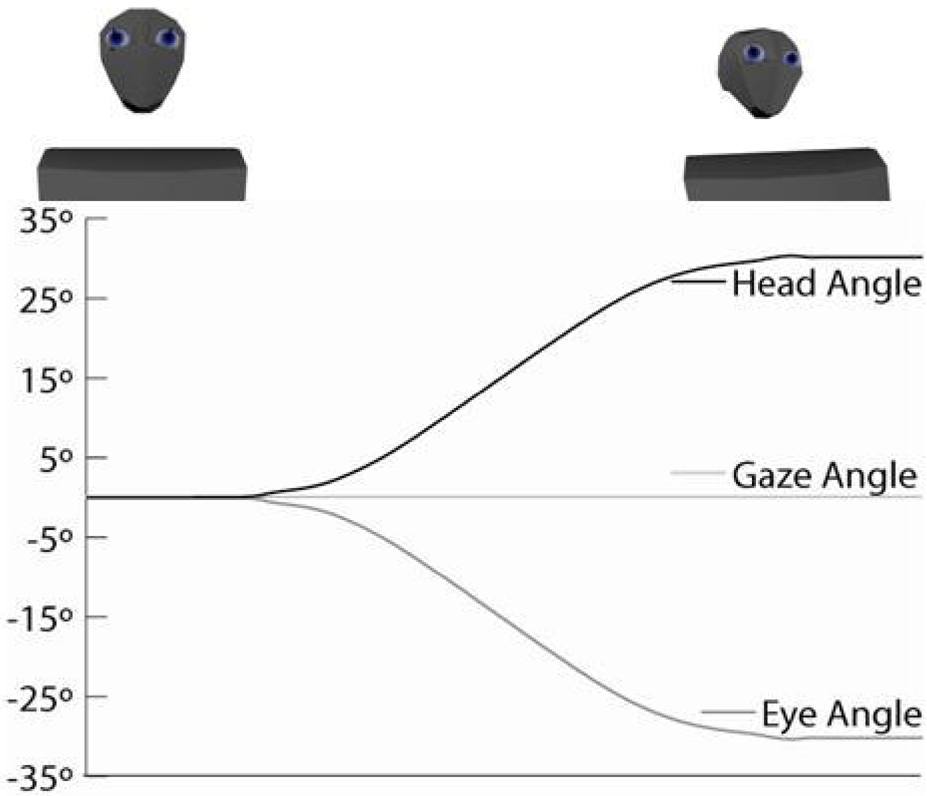

Figure 4-2: Vestibulo-Ocular Reflex

4.2.3 Eye-Head Combined Movement

The combined eye-head saccade (shown in Figures 4-3 and 4-4) integrates eye movement and head-torso movement. There are two versions of the eye-head saccade, and both are generated similarly. First, the head and torso movement is generated through applying GWTs to emotionally neutral gaze shifts, and then the eye movement is generated based on the movement of the head and the stereotypical representation of eye-head saccades. For eye-head saccades of less than 45º, the position of the eye is determined by generating a stereotypical saccade to the target once the head has turned more than 1º away from its starting location.

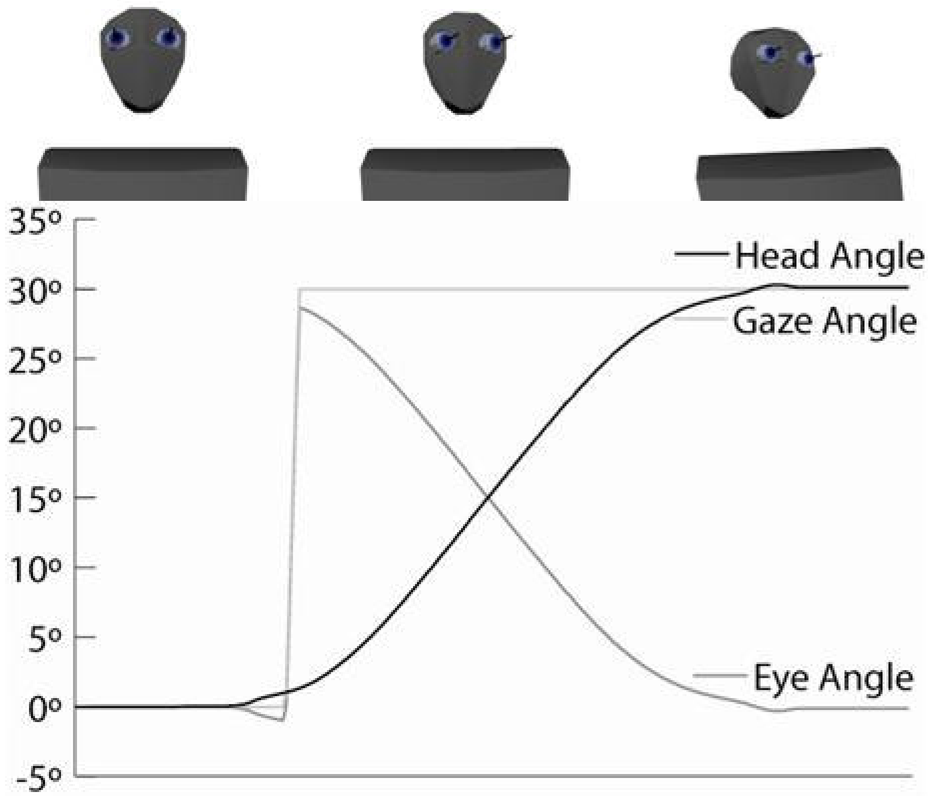

Figure 4-3: Eye-Head Saccade Within Motor Limit

While gaze-onset studies have shown that the eye actually begins to move before the head, by basing the eye movement on an easily detectable feature such as this it becomes easier to layer the eye movement onto the head movement in an interactive environment. Once the eye has reached its target, the VOR will keep the eyes on target as the head slowly turns to the target [Gresty, 1974], [Guitton & Volle, 1987], [Leigh & Zee, 2006]. The small images above the graph show the character at the beginning of the movement, then just after the saccade has occurred and the VOR is taking control of the eye movement, and then finally at the end of the gaze shift.

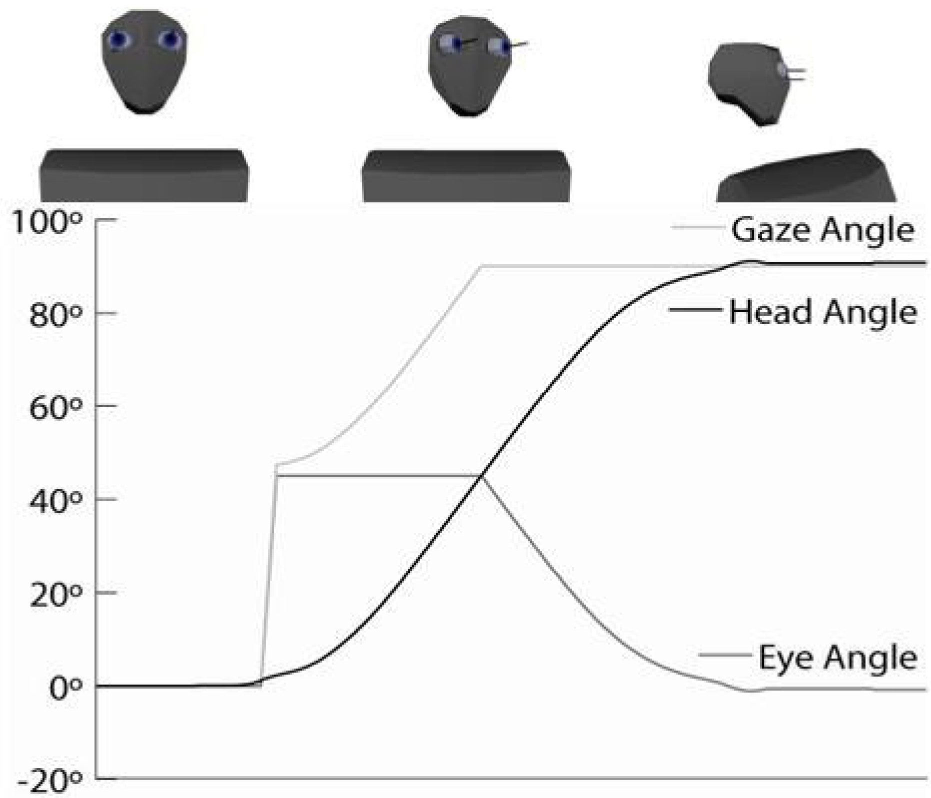

Figure 4-4: Eye-Head Saccade Beyond Motor Limit

When looking at a target beyond the saccade limit of +-45º, the combined eye-head saccade is slightly different, as seen in Figure 4-4. In this case, after the emotionally expressive head and torso movement is generated, the position of the eye is determined by performing a stereotypical saccade to the maximum of 45º once the head has turned more than 1º away from its starting location. The eye will then remain in that orientation, relative to the head; until the head has rotated enough that the eye is on target. At that time, the VOR takes effect, and the eye remains on target until the head movement has terminated. The character above the diagram shows first the initial position of the gaze, then the gaze at the end of the 45º saccade, and finally the terminal position of the gaze shift. When an actual human performs an eye-head saccade, the VOR effect will often not be large enough to match the rotation of the head. In this case, very small saccades will occur, keeping the eye on target [Guitton & Volle, 1987]. However, this effect is not modeled as these saccades are too small to be noticed by a casual observer.

4.3 The Expressive Gaze Model

These two components, the Gaze Warping Transformation (GWT) and the procedural model of gaze make up the Expressive Gaze Model (EGM), which can display arbitrary expressive behaviors towards an arbitrary target.

The purpose of this model is to ultimately allow agents with highly complex models of affect to display their internal state through gaze. Therefore, in addition to the production of single expressive gaze shifts, this model allows for more subtle and complex displays of affect through sequential combinations of gaze shifts of different types, all displaying the same emotion. For example, compare the gaze shifts in Figure 4-5 and Figure 4-6. In Figure 4-5, the character makes a single eye-head saccade turning away to the side, with a slumped posture and down-turned head.

By comparison, in Figure 4-6 the character produces the same gaze shift, in the same emotional state, through the sequential combination of three individual gaze shifts. The character starts by making the same eye-head saccade shift away to the side with slumped posture and down-turned head. After turning 75% of the way to the final target, the character pauses, and shoots a quick saccade back towards the

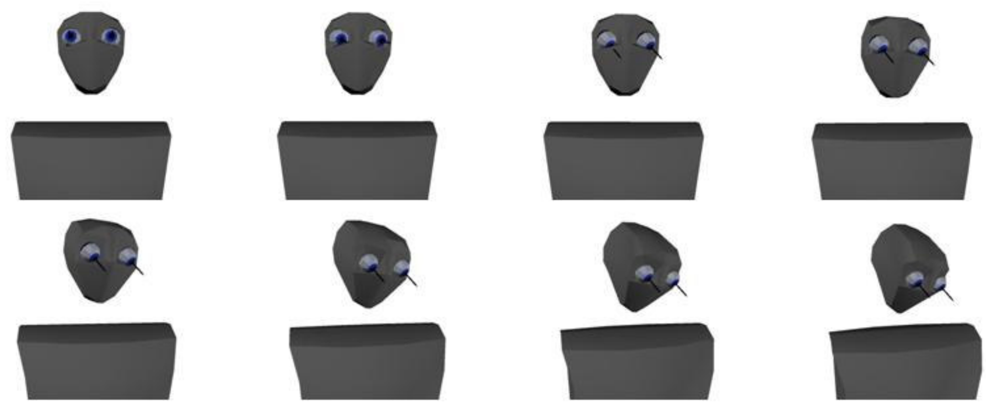

Figure 4-5: Single Gaze Shift

observer. At the end of this pause, the character performs a final eye-head saccade, ending at the same point as the previous gaze shift.

Through the ability to generate single and multiple gaze shifts of arbitrary behaviors directed at arbitrary emotional states, the Expressive Gaze Model provides the ability to produce emotionally expressive gaze for highly complex affective states.

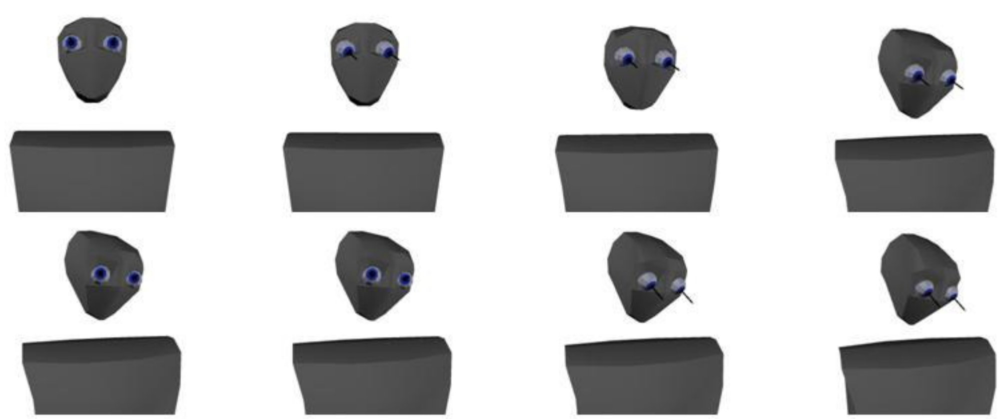

Figure 4-6: Multiple Gaze Shifts

Chapter 5 Mapping Between Behaviors and Emotions

5.1 Overview

The goal behind the Expressive Gaze Model is to produce emotionally expressive gaze shifts with a minimum of motion capture data. The most intuitive way to use the EGM to do this would be to have a Gaze Warping Transformation for each desired emotional state, and then apply that emotional GWT to an emotionally neutral gaze shift directed towards an arbitrary target. However, this method only allows the model to generate emotional gaze in a pinpoint, nearest-neighbor fashion. It also requires motion capture data for each emotional state, which may be difficult to obtain, and does not predict the attribution of emotion to behaviors outside of these specific emotional states.

This section describes an empirical study that provides an alternative to this pinpoint mapping between gaze behavior and emotion. As described in the Introduction, this study answers the question: "Is there a relationship between the composition of low-level gaze behaviors into complex, expressive gaze shifts, and the composition of low level emotional dimensions into complex emotional states such that it can be reliably predicted how a viewer will attribute emotion to a gaze shift generated by composing low level behaviors?" Thus, the goal of this approach is to obtain a set of low-level gaze behaviors annotated with emotional data that are then combined according to a dimensional model of emotion such that the attribution of emotion to the resulting gaze shift can be predicted. This will allow the generation of a broader array of emotional responses while using a smaller library of

GWTs derived from a smaller number of motion captures than would a pinpoint method of mapping between behavior and emotion.

However, this raises the question, why perform an empirical study at all? Why not just use the mappings between emotion and behavior already reported in the nonverbal behavior literature? Unfortunately, the relationship between behavior and emotion in this literature is still too unclear to simply use it as a mapping. This is due to a number of factors. First, it is not known exactly how behavior expresses emotion. While many behaviors have been shown to be expressive, it is not always clear what is expressed. For example, head angle can express both dominance and pleasure [Mignault & Chaudhury, 2003].

Second, even if reliable maps existed between emotion and behavior, it would not necessarily follow that GWTs drawn from motion captures of these behaviors would necessarily replicate those results. For example, an actor could perform behaviors in a subtly idiosyncratic fashion, leading to a different interpretation of the behavior by an observer. Additionally, given the knowledge of how behaviors express emotion does not provide a mapping describing how combinations of those behaviors express emotion. Finally, the psychology literature does not provide the dynamics for a behavior. For example, while turning the head down can display a lack of dominance, it is unclear how much the head should be turned down, or how quickly the turn should be performed.

For these reasons, the empirical study was performed based on the "reverse engineering" approach of [Grammer & Oberzaucher, 2006]. In this context, "reverse engineering" is used to mean a non-interpretive bottom-up approach where nonverbal behavior expressions are generated through the combination of low-level physical behaviors, and then displayed to coders who rate the expression on its emotional content. The goal of [Grammer & Oberzaucher, 2006]'s work was to obtain an emotional annotation of Facial Action Coding System (FACS) Action Units (described in [Ekman & Rosenberg, 2004]) in order to predict the attribution of emotion to a complex facial expression generated from the combination of emotionally annotated Action Units. Specifically, [Grammer & Oberzaucher, 2006] used Poser – a 3d human model animation suite – to generate random facial expressions from the space of all possible combinations of FACS Action Units. Users then evaluated the resulting expressions using the circumplex model of emotion – a two-dimensional model of emotion based on the dimensions Valence and Arousal – providing a mapping between the expressive behavior space defined by the FACS Action Units, and the emotional space defined by the circumplex model.

Similarly, in this study, a set of low-level behaviors were culled from the nonverbal behavior literature, and gaze animations of combinations of these gaze behaviors have been generated using the Expressive Gaze Model. Finally, subjects attributed emotion to animated characters displaying these behaviors during gaze shifts. The subjects first rated the gaze animations by emotional category, such as anger or fear. Then, they evaluated the animations evaluated according to the PAD dimensional model of emotion [Mehrabian, 1981].

The results of this reverse engineering study show that these low-level gaze behaviors, when annotated with emotional dimensional values and combined in accordance with those dimensions, display the combined emotions and predict the attributed emotional category for the emotions of Excitement, Contempt, Sadness, and Grief. The study provides a preliminary mapping between low-level gaze behaviors and emotional dimensions, clearly demonstrates the utility of the GWT as a research tool beyond generating animations, and points out several areas for future research.

While the results of this study are most relevant to the Expressive Gaze Model, any procedural gaze model with sufficient control over the animation curves used to generate gaze shifts should be able to take advantage of this mapping.

5.2 Structure of Gaze Behavior Model

In order to use this reverse engineering approach, a set of gaze behaviors to reproduce in animations is required. Given the lack of a descriptive set of known gaze behaviors analogous to the FACS system used by [Grammer & Oberzaucher, 2006], a set of emotional behaviors from the psychology and arts literature that are likely to convey emotional state were identified (Table 5-1).

Because the emphasis of this work is on generating emotional behaviors that can be correctly recognized by observers and associating these behaviors with emotions using a bottom-up behavior-based method, the focus here is on the identification of a space of behaviors that can be used to express emotion in gaze, not on what emotional states these behaviors actually display.

Table 5-1: Gaze Behaviors

Hypothesized Behaviors
Head turns upwards
Head turns downwards
Faster movement
Slower movement
Upright posture
Hunched posture

For example, [Migault & Chaudhury, 2003], and [Carney et al., 2005], show that head vertical angle is important to the display of dominance and of pleasure. In addition, previous research shows that the perception of arousal is strongly related to velocity [Lance & Marsella, 2007], and that vertical torso posture is important to the expression of emotion [Schouwstra & Hoogstraten, 1995], [Carney, 2005], [Coulson, 2004]. While there are many alternative gaze behaviors that could also be modeled using the GWT, such as subtle variations in dynamics, or wider variations on posture, this limited set provides a starting point for this research.

5.3 Generating Gaze Warping Transformations

For each of these gaze behaviors, the actor was asked to perform “high,” “neutral,” and “low” versions of the behavior, and motion data was collected from the resulting movement. All captured gaze shifts consisted of the desired behavior being displayed in a gaze aversion that started gazing straight ahead in a neutral position and posture, and ended gazing 30 degrees to the right displaying the intended gaze behavior. However, the “high” torso posture was indistinguishable from the neutral torso posture due to the limitations of the motion tracking system, resulting in the set of physical behaviors shown in Table 5-2. From that motion data, eight GWTs were then produced, one for each behavior listed in Table 5-2.

Table 5-2: Discretization of Gaze Behaviors

Behavior	Possible Parameter Values
Head Posture	Raised, Neutral, Bowed
Torso Posture	Neutral, Bowed
Movement Velocity	Fast, Neutral, Slow

Motion capture of the different gaze types (Table 5-3) was also collected, and neutral gaze shifts for each gaze type were produced. The gaze types were captured both as gaze aversions that began gazing straight ahead and ended gazing 30° to the right, and as gaze attractions that began 30 degrees to the right and ended gazing straight ahead. This resulted in 10 neutral gaze shifts – one aversive and one attractive gaze shift for each of the different types of gaze in Table 5-3.

5.4 Generating Animations

From these 8 GWTs representing physical behaviors (Table 5-2) and 10 neutral gaze shifts representing the various gaze types (Table 5-3), 150 animations were generated for use in the empirical bottom-up study, as follows: GWTs of the gaze behaviors in Table 5-2 were combined in all possible ways, leaving out combinations of a raised head with bowed torso due to the physical implausibility of the behavior. This resulted in 15 total behavior combinations (see Table 5-4). Then, these 15 behavior combination GWTs transformed the 10 neutral gaze shifts representing the various gaze types, resulting in 150 gaze shift animations. The full table of gaze shifts can be seen in Appendix H, and the GWTs representing the 15 behavior combinations can be seen in Appendix K.

Table 5-3: List of Gaze Types

Gaze Type
Eye-Only Shift
Eye-Head Shift
Eye-Head-Body Shift
Head-Only Movement
Head-Body Movement

However, due to uncertainty about how the GWTs would combine with the different types of neutral gaze shifts, GWTs that were taken from a certain type of gaze shift were applied only to that type of gaze shift. Therefore, Head-Only and Head-Body GWTs were actually captured for all of the different gaze behaviors. For example, Head-Only behavior GWTs were applied to Head-Only and Head-Eye neutral gaze shifts, and Head-Body behavior GWTs were applied to Head-Body and Eye-Head-Body neutral gaze shifts. Finally, Head-Only behavior GWTs were applied to Eye-Only neutral gaze shifts. The result is a gaze shift where the eye changes target, but the head and torso display emotional gaze behavior without changing target.

Table 5-4: Combinations of Gaze Behaviors

Head Posture	Torso Posture	Movement Velocity	Label
Raised	Neutral	Fast	RNF
Raised	Neutral	Neutral	RNN
Raised	Neutral	Slow	RNS
Neutral	Neutral	Fast	NNF
Neutral	Neutral	Neutral	NNN
Neutral	Neutral	Slow	NNS
Neutral	Bowed	Fast	NBF
Neutral	Bowed	Neutral	NBN
Neutral	Bowed	Slow	NBS
Bowed	Neutral	Fast	BNF
Bowed	Neutral	Neutral	BNN
Bowed	Neutral	Slow	BNS
Bowed	Bowed	Fast	BBF
Bowed	Bowed	Neutral	BBN
Bowed	Bowed	Slow	BBS

Once the behavioral GWTs were applied to the different gaze types, all of the resulting gaze shifts were imported into Maya and rendered. Originally, two separate sets of gaze shifts were rendered, although only one set was used for the study. These two sets of behavior are referred to as "Within Emotion Behaviors" and "Into Emotion Behaviors." The Into Emotion Behaviors are determined from motion captures of the actor beginning in a neutral position, and ending displaying the intended gaze behavior. The Within Emotion Behaviors are from movements where the actor both begins and ends displaying the gaze behavior. For the evaluation, the set of animations produced from the Into Emotion Behaviors are used, as these animations show a clearly emotional reaction to a stimulus. The Within Emotion Behaviors are more subtle, more difficult to read, and may display the characters' mood or personality more than their emotional state. However, despite the fact that the Within Emotional Behaviors were not evaluated, they are still useful not only for displaying mood or personality, but for performing multiple gaze shifts displaying the same behavior after an initial Into Emotion Behavior gaze.

5.4.1 Combining Gaze Warping Transformations

The process used for combining the GWTs of the individual gaze behaviors into the combinations listed in Table 5-4 was very simple, and followed from the definition of the GWT parameterization. Recall that the GWT parameterization is a set of (c,b) pairs, where c is a scaling factor that modifies the timing of the animation, and b is a displacement factor that modifies the amplitude of the movement. The simplest way to combine GWTs would be to multiply the timing scaling factors, and sum the spatial displacement values. This method is used, with one change. If the GWT is not a velocity-affecting GWT, its velocity scaling factor c is set to 1 before it is multiplied. The GWTs are combined this way so that combining multiple GWTs that are not intended to affect the velocity of the gaze behavior does not actually result in a velocity change. For instance, if several GWTs that are not intended to explicitly affect velocity, but that are all slightly slower than normal velocity are combined, the result could be a gaze shift noticeably slower than normal speed.

There are two reasons why this is not a concern with the spatial displacement factor b. The first is that b is an additive factor, not a multiplicative factor like the velocity scaling factor c is. In addition, the inverse kinematic (IK) constraint system will handle spatial displacements that result in movement beyond the capabilities of a human body, while the IK system will not handle abnormal movement velocities. The two following GWTs will be used to exemplify combining Gaze Warping Transformations.

$$g_1 = \begin{bmatrix} c_1, b_{11} & c_2, b_{12} \\ c_1, b_{21} & c_2, b_{22} \end{bmatrix}$$

$$g_2 = \begin{bmatrix} d_1, e_{11} & d_2, e_{12} \\ d_1, e_{21} & d_2, e_{22} \end{bmatrix} \tag{1}$$

If neither of the GWTs is explicitly intended to modify the velocity of the gaze shift, as is the case when combining a head bowed behavior with a bowed torso behavior, then the GWT g_c resulting from the combination of g_1 and g_2 is:

$$g_c = \begin{bmatrix} 1, b_{11} + e_{11} & 1, b_{12} + e_{12} \\ 1, b_{21} + e_{21} & 1, b_{22} + e_{22} \end{bmatrix} \quad (2)$$

However, if one of the GWTs, in this case g_1, is explicitly intended to modify the velocity of the gaze shift, the GWTs are combined as follows:

$$g_c = \begin{bmatrix} c_1, b_{11} + e_{11} & c_2, b_{12} + e_{12} \\ c_1, b_{21} + e_{21} & c_2, b_{22} + e_{22} \end{bmatrix} \quad (3)$$

5.5 Online Data Collection

Once the animations were generated, two online data collections to map these gaze behaviors onto affective states and dimensions were performed. The first was a preliminary collection, obtaining open-response data. This data then determined the categorization for the second forced-choice collection.

5.5.1 Open-Response Collection

The goal of this preliminary data collection was to determine the categories for the primary data collection, and obtain a picture of how well the animated gaze behaviors covered the emotional space defined by the selected emotion models.

Approach. 31 subjects each viewed 20 animations randomly selected from the set of 150 animations with no duplicates and provided an open-ended written response to the question "What emotional state is the character displaying?" This resulted in 620 views, or approximately 4 per animation. The affective responses were categorized based on a hierarchical model of emotion [Metts & Bowers, 1994].

Results. The hierarchical model, [Metts & Bowers, 1994], acted as a sorting guideline to divide the many individual responses into ten discrete categories (Table

5-5); for example categorizing “expression of contempt” as Contempt, or “terrified” as Fear. Nevertheless, there were additional categories that were common in the subject’s open ended responses that were not described by the hierarchical model which are included in Table 5-5. After categorizing the responses, the selection was narrowed to the categories with at least one video with 50% agreement across raters for that category.

The selection was further narrowed to those categories that were not related to attention, discarding responses such as “change in attention,” “displaying strong interest,” and “distracted.” This was done because gaze by itself is a strong indicator of interest, attention, and distraction. The concern was that these types of categories would become “catch-alls,” drawing a disproportionate response during the forced-choice selection. Finally, the category indicating “uncertainty” was discarded, due to the concern that it would be applied when the subject was uncertain of the character’s state, not when the character was displaying uncertainty. The full list of responses can be seen in Appendix I.

Table 5-5: Emotional Categories

Emotional Categories
Anger
Contempt
Disbelief
Excitement
Fear
Flirtatious
Guilt
Sadness
Secretive
Surprise

Table 5-6: Emotional Dimension Rating Scales

Emotional Dimension	Rating Statement
High Dominance	The character is dominant.
Low Dominance	The character is submissive.
High Arousal	The character is agitated.
Low Arousal	The character is relaxed.
High Valence	The character is pleased.
Low Valence	The character is displeased.

5.5.2 Forced-Choice Collection

After selecting the low-level behaviors, generating the animations, and setting the emotional categories, the empirical study was performed. The animations were placed online, and subjects rated the animation in two ways: first by selecting the emotional category (Table 5-5) that most closely approximated the emotion that they perceived in the animation, and second by locating the animation's perceived emotion along the emotional dimensions of the PAD model.

Subjects rated the animation's location within the PAD model by using five-point scales to indicate their agreement with two statements representing each dimension, seen in Table 5-6. The scale items were 1 = Strongly Disagree, 2 = Disagree, 3 = N/A, 4 = Agree, 5 = Strongly Agree. Both emotional categories and rating statements were displayed in random order for each animation. One hundred people each rated fifteen unique, randomly selected animations, resulting in ten ratings for each of the 150 animations.

Finally, the subjects were asked if the animated character was performing a gaze attraction or an aversion. In addition, demographic information was obtained, specifically age, gender, and ethnicity. The questionnaire is in Appendix C.

5.6 Mapping Between Gaze Behaviors and Emotion

The analysis of this data was intended to answer the following questions:

1. How do the emotional dimensions relate to the low-level gaze behaviors in Table 5-2?
2. Can low-level gaze behaviors be combined within the PAD dimensions?
3. Can low-level gaze behaviors be combined across PAD dimensions into emotional categories?

While the original intent was to find which of the 150 individual animations varied across emotional state, ten ratings per animation were too few to perform a reliable statistical analysis. Instead, as there were no significant differences across gaze type (Table 5-3), the gaze shifts were combined across gaze type, resulting in 50 ratings for each of the 15 combinations of gaze behaviors (Table 5-4).

5.6.1 Dimensional Results

Before performing an analysis of the collected data, it was necessary to determine the reliability of the dimensional rating scales. To quantify this, the correlation and Cronbach's Alpha were calculated between each pair of rating scales from Table 5-6.

The Pleased and inverted Displeased scales performed well. The correlation between the two was 0.615, and the standardized Alpha score indicating scale reliability was high, with $\alpha = 0.7610$, ($\alpha > 0.7$ is considered a reliable scale). Dominant and inverted Submission also did well, with a correlation of 0.6649, and a high Alpha ($\alpha = 0.7987$). Therefore, the Pleased and inverted Displeased were averaged into a single Pleasure scale, and Dominant and inverted Submission were combined into a single Dominance scale. Correlations between the Dominance and Pleasure scales were low, (0.1569), indicating no overlap.

However using the ratings of Relaxed and Agitated as a scale for Arousal was less successful, as both correlation and Alpha were low (correlation = 0.3745, α = 0.5449). In addition, correlations between Relaxed and Pleased were higher than between Relaxed and Agitated (0.5353), as were correlations between Agitated and Displeased (0.4889). There are several possible explanations for this, and further research will be necessary to determine the actual reason. For the remainder of this paper, the two scales are used separately as Relaxed and Agitated.

As the data was collected using 5-point scales, but only 3-point scales of physical behavior were animated, the collected data was condensed down into 3-point scales by combining "Strongly Disagree" and "Disagree", as well as "Strongly Agree" and "Agree", leaving Neutral ratings unchanged.

How do the emotional dimensions relate to the low-level behaviors in Table 5-2?

A series of MANOVAs (multivariate analysis of variance) and post-hoc tests determined whether or not the mean emotion dimensions ratings differed across the low level behaviors found in Table 5-2. Four MANOVAs were performed, each with one dimension (Pleasure, Agitation, Relaxation, or Dominance) as the dependent variable, and Head Orientation, Torso Orientation, Velocity, and Subject as the independent variables, while testing for second degree factorial interaction between the independent variables. Results of this analysis can be seen in Table 5-7.

Table 5-7: Significant Relationships between Emotional Dimensions and Low-Level Gaze Behaviors

Emotional Dimension	Head	Torso	Velocity
High Dominance	Raised	Bowed	Fast
Low Dominance	Bowed	Neutral	Non-Fast
Relaxed		Bowed	
Agitated	Non-Bowed		Fast
High Pleasure	Neutral	Bowed	
Low Pleasure	Non-Neutral	Neutral	

As shown in Rows 1 and 2 of Table 5-7, the ratings for Dominance attributed to gaze shifts significantly differed across differing Head Orientation, Torso Orientation, and Velocities. The MANOVA results for Dominance showed significant effects ($N = 1500$, $DF = 18$, $F = 14.5110$, $p < .001$) for head orientation ($F = 24.0776$, $p < .001$), torso orientation ($F = 82.5508$, $p < .001$), and velocity ($F = 7.3838$, $p < .001$), with a significant interaction between head and torso orientation ($F = 6.4689$, $p < .05$).

In addition, Rows 1 and 2 show the results of the post-hoc tests. These tests showed clear differences between group means, with higher Dominance ratings corresponding to raised head behaviors, and lower Dominance ratings corresponding to bowed head behaviors. In addition, the post-hoc tests revealed that a bowed posture was rated as higher Dominance, and a neutral posture was rated for lower Dominance. Finally, the Dominance rating for fast movements was higher than that for slow or for neutral movements (all results significant to $p < .01$).

In contrast, Row 3 displays the post-hoc tests results showing that the Relaxed dimension only significantly differs across torso orientation, with gaze shifts displaying a bowed torso drawing significantly higher Relaxed ratings from subjects ($p < .01$). However, MANOVA results showed significant differences ($N = 1500$, DF = 18, $F = 1.8892$, $p < .05$) across both the torso orientation ($F = 11.4132$, $p < .001$) and the velocity ($F = 3.7849$, $p < .05$), with a significant interaction effect between torso and velocity ($F = 3.6755$) $p < .05$). The post-hoc tests did not reveal useful information about the velocity, indicating that the significant difference found by the MANOVA was likely related to the interaction between torso and velocity.

Row 4 shows the post-hoc test results that raised and neutral head orientations were rated as significantly more Agitated than bowed head orientation, and that the Agitated rating for high velocity was higher than that for slow or neutral ($p < .05$). The MANOVA for Agitation found significant differences (N = 1500, DF = 18, $F = 4.5978$, $p < .001$) across the head orientation ($F = 19.6129$, $p < .001$), the velocity ($F = 6.0387$, $p < .01$), and the viewer ($F = 17.1201$, $p < .001$), and a significant interaction effect between the head and the velocity ($F = 7.1696$, $p < .05$).

Finally, post-hoc tests ($p < .01$) revealed that the Pleasure rating for a neutral head orientation was significantly higher than those for bowed and raised head orientations, and that a bowed posture received significantly higher Pleasure ratings than a neutral posture, as shown in Rows 5 and 6. The MANOVA showed that Pleasure significantly differed (N = 1500, DF = 18, $F = 5.9261$, $p < .001$) across both the vertical orientation of the head ($F = 6.5836$, $p < .05$) and the torso ($F = 77.5703$, $p < .001$), with no significant interaction effects. The ratings for Pleasure also differed significantly ($F = 4.0601$, $p < .05$) across viewer.

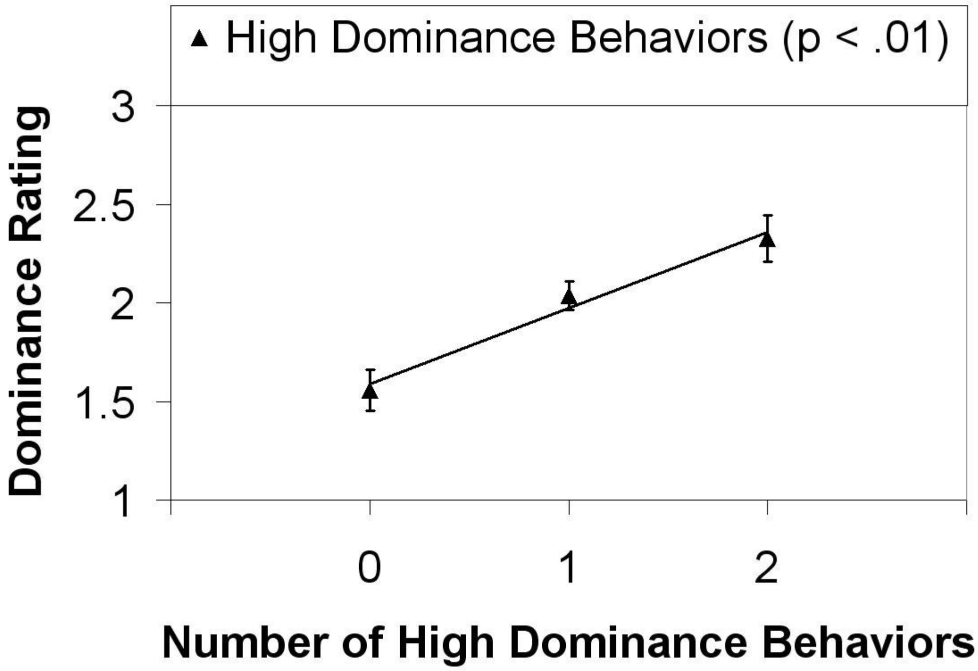

Figure 5-1: Mean Dominance Rating vs. Number of High Dominance Behaviors

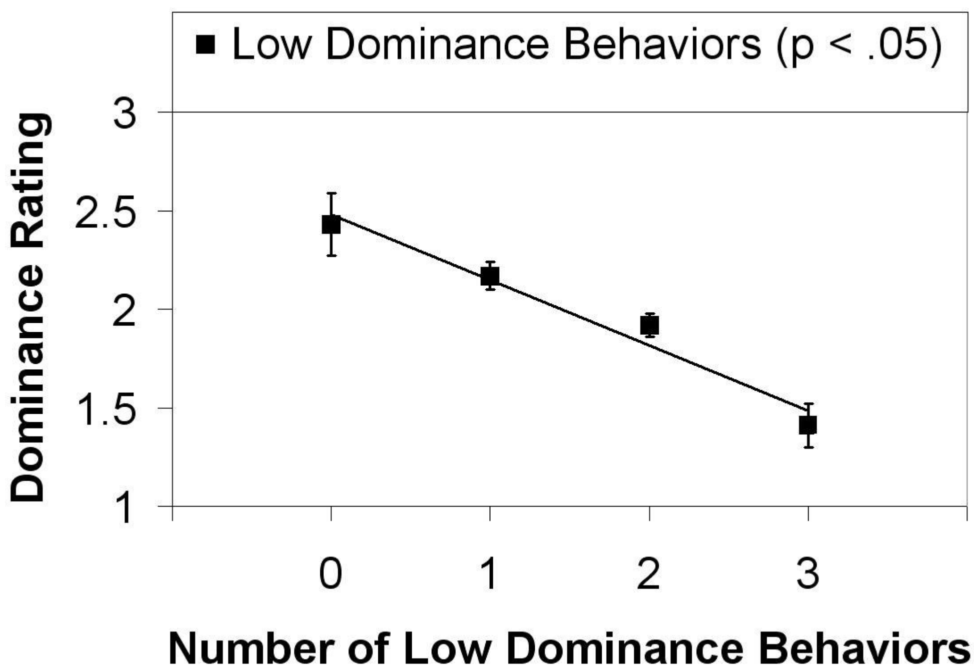

Figure 5-2: Mean Dominance Rating vs. Number of Low Dominance Behaviors

Can low-level gaze behaviors be combined within the PAD dimensions?

In order to determine whether or not the low-level behaviors can be combined within individual PAD dimensions, a second analysis tested whether or not gaze shifts displaying different numbers of behaviors significantly related to a specific emotional dimension would have different ratings for that dimension attributed to them. For example, does the mean Dominance rating of a gaze shift that displays one Low Dominance behavior significantly differ from the mean Dominance rating of a gaze shift that displays two Low Dominance behaviors? In turn, do these ratings significantly differ from a gaze shift that displays 3 Low Dominance behaviors?

For this analysis, four MANOVAs were performed. Each MANOVA used an emotional dimension (Dominance, Relaxed, Agitated, and Pleasure) as the dependent variable, while the independent variables were the number of behaviors associated with that emotional dimension, and the subject. Thus, one MANOVA had Dominance as a dependent variable, while the independent variables were the number of low dominance behaviors, the number of high dominance behaviors, and the subject. The results of this analysis clearly showed that mean attributed ratings for an emotional dimension increased as the number of gaze behaviors associated with that emotional dimension increased, as seen in Figures 5-1 through 5-5. This indicates that physical gaze behaviors, when combined according to PAD dimensions will be rated as predicted by the combined behaviors.

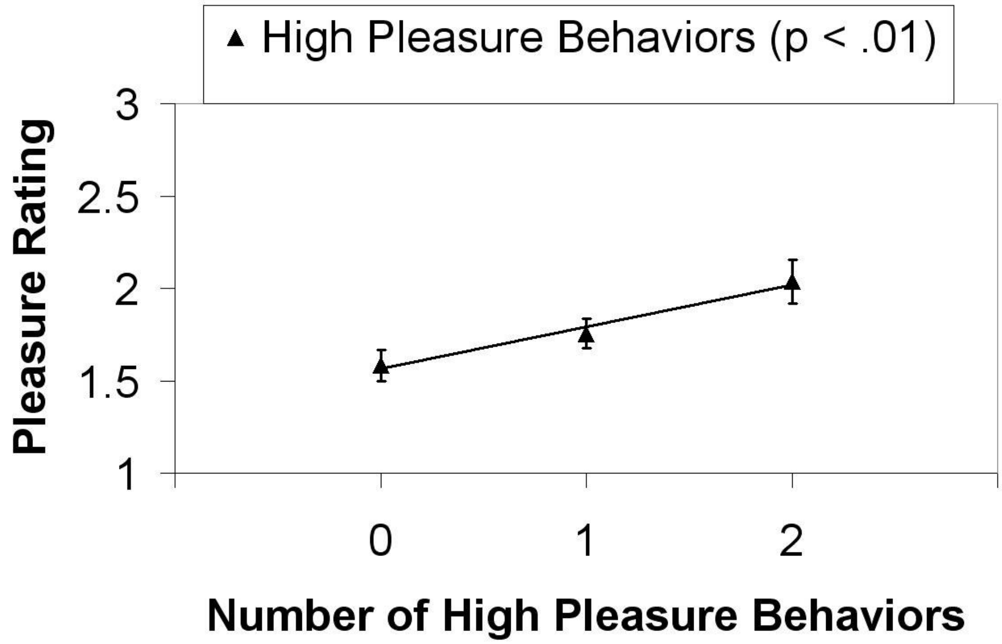

Figure 5-3: Mean Pleasure Rating vs. Number of High Pleasure Behaviors

Figure 5-4: Mean Pleasure Rating vs. Number of Low Pleasure Behaviors

The specific results for Dominance show that there were significant differences ($N = 1500$, $DF = 6$, $F = 32.2426$, $p < .01$) across the number of both Low ($F = 14.1668$, $p < .001$) and High Dominance ($F = 26.3914$, $p < .001$) behaviors displayed in a gaze shift, and a significant ($F = 6.9287$, $p < .01$) interaction effect between Low and High Dominance. Post-hoc tests showed that as the number of High Dominance gaze behaviors displayed in a gaze shift increased, the mean rating of Dominance for that gaze shift significantly increased ($p < .01$) as well (Figure 5-1). In contrast, as the number of Low Dominance behaviors increased, the mean rating of Dominance for that gaze shift significantly decreased (Figure 5-2).

The mean Pleasure rating showed significant differences across the number of both Low and High Pleasure behaviors displayed in a gaze shift ($N = 1500$, $DF = 3$, $F = 22.9619$, $p < .001$), although there were also significant differences across viewers ($F = 4.8669$, $p < .05$), and no interaction effects. Subsequent post-hoc tests showed that mean ratings of Pleasure significantly increased ($p < .01$) as the number of High Pleasure behaviors displayed in a gaze shift increased (Figure 5-3); and that mean ratings of Pleasure significantly decreased ($p < .01$) as the number of Low Pleasure behaviors increased (Figure 5-4).

The MANOVA for Agitated revealed that there were again significant differences across the number of behaviors ($N = 1500$, $DF = 3$, $F = 18.3058$, $p < .001$) displayed in a shift, but also showed significant differences across viewers ($F = 20.5002$, $p < .001$), although there were no interaction effects. The post-hoc tests demonstrated that gaze shifts with zero or one Agitated behaviors were rated as significantly less Agitated than those shifts with two Agitated behaviors ($p < .01$), although the difference between zero and one behaviors was not significant (see Figure 5-5).

As the relaxed dimension only had one behavior associated with it, no further testing was performed.

5.6.2 Categorical Results

Can low-level gaze behaviors be combined across PAD dimensions into emotional categories?

To examine the relationships between low level gaze behaviors and emotional categories in the data, a cross tabulation was generated, and the Pearson's chi squared (X^2) test was performed on the cross tabulation.

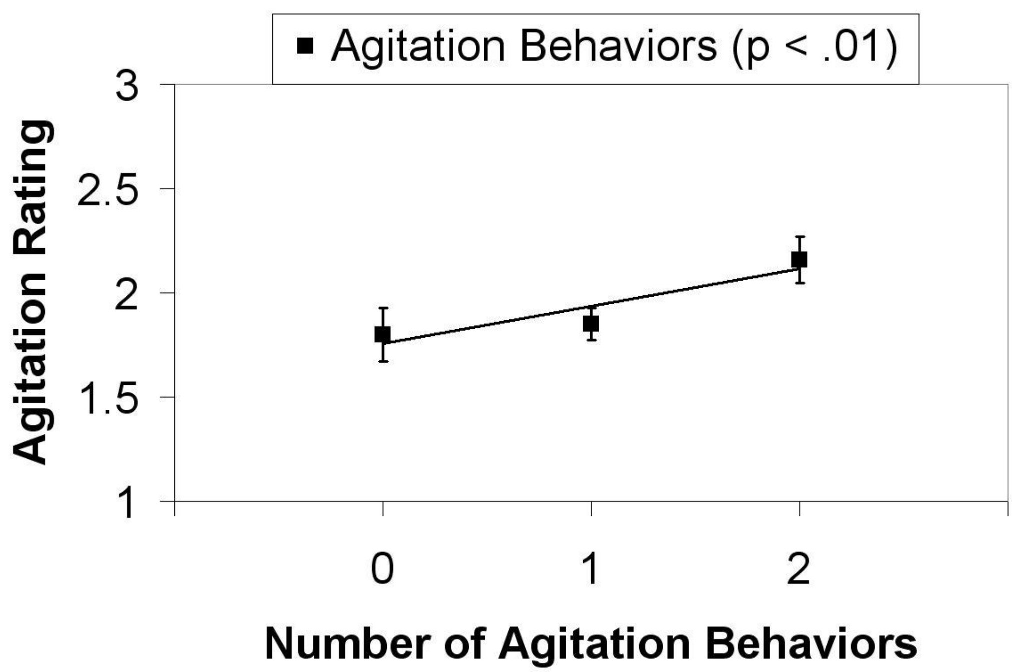

Figure 5-5: Mean Agitation rating vs. Number of Agitation Behaviors

Table 5-8: Emotional Categories and Significantly Related Behavior Combinations

Emotional Categories	Significantly Related Behavior Combinations
Contempt	Head Raised, Torso Neutral, Velocity Neutral
Excitement	Head Neutral, Torso Bowed, Velocity Fast
Fear	Head Neutral, Torso Neutral, Velocity Neutral Head Neutral, Torso Neutral, Velocity Slow
Guilt	Head Bowed, Torso Neutral, Velocity Neutral Head Bowed, Torso Neutral, Velocity Slow
Sadness	Head Bowed, Torso Neutral, Velocity Fast Head Bowed, Torso Neutral, Velocity Neutral

After performing the X^2 tests on the entire cross tab, further tests were performed on the residuals to determine which had significant differences. Results of the analysis of emotion categories can be seen in Table 5-8. The X^2 test for the entire cross tab showed that the gaze combinations and the emotional categories were not randomly related ($N = 1500$, $DF = 126$, $X^2 = 775.817$, $p < .001$).

The rows in Table 5-8 show behavior combinations (Table 5-4) that had residuals with a significantly high number ($p < .05$) of ratings for that emotional category (Table 5-5). For example, Contempt was significantly associated with the gaze behavior combination of Raised Head, Neutral Torso, and Neutral Velocity, while Excitement was significantly associated with the combination of a Neutral Head, Bowed Torso, and Fast Velocity.

Table 5-9: Significant Relationships between Emotional Categories and Gaze Behaviors

Emotional Category	Head	Torso
Contempt	Raised	Neutral
Excitement		Bowed
Fear		Neutral
Flirtatious	Bowed	
Guilt	Bowed	Neutral
Sadness	Bowed	
Surprise	Not Bowed	

While only 5 of the 15 gaze behavior combinations from Table 5-4 had significant associations to emotional categories, it was clear through examination of the residuals that further analysis of the relationship between the emotional categories and the low-level behaviors from Table 5-2 could be useful. For example, while no individual gaze behavior combination was rated significantly high for Flirtatious, all of the gaze shifts with the bowed head behavior had more Flirtatious ratings than all of the gaze shifts without bowed head. The results of this analysis can be seen in Table 5-9.

A number of significant interactions were found between head vertical orientation, and the emotional categories, ($N = 1500$, $DF = 18$, $X^2 = 379.470$, $p < .001$). Torso posture was also not randomly related to emotional category ($N = 1500$, $DF = 9$, $X^2 = 187.490$, $p < .001$). However, no strong relationships were found between the emotional categories and the velocity of the gaze using a cross tab analysis of emotions by velocity. While the X^2 test rejected the null hypothesis that emotional category and velocity are only randomly related ($N = 1500$, $DF = 18$, $X^2 = 42.361$, $p < .001$), upon examination of the residuals, no emotional categories significantly differed across velocities.

Testing the residuals showed that the Contempt category was more likely to be attributed to a gaze shift with the head raised behavior ($X^2 = 70.3475$, $p < .01$), as well as more likely to be attributed to a gaze shift with a neutral torso animation ($X^2 = 24.2387$, $p < .01$). Counter-intuitively, Excitement was more likely to have a bowed torso ($X^2 = 62.9468$, $p < .01$), while Fear ($X^2 = 29.1892$) was more likely to be rated to neutral torso animations. Flirtatious was more likely to be attributed to gaze shifts displaying a bowed head ($X^2 = 73.4133$, $p < .01$), and Guilt was more likely to be attributed to bowed head gaze shifts ($X^2 = 81.3333$, $p < .01$), as well as gaze shifts with a neutral torso posture ($X^2 = 19.8775$, $p < .01$). Sadness was also more likely to be associated with a bowed head ($X^2 = 42.5104$, $p < .01$). Finally, Surprise was significantly less likely to be attributed to bowed head gazes than it was to gaze shifts that displayed neutral or raised head behavior ($X^2 = 55.3014$, $p < .01$).

5.7 Discussion

The goal of this reverse engineering study was to attribute emotional state to low-level gaze behaviors, and then test whether or not gaze shifts generated by composing these behaviors would have similar emotions attributed to them. The results, while preliminary, are highly promising. The foremost result is that individual gaze behaviors can be associated with individual dimensions in the Pleasure-Arousal-Dominance space (Table 5-7).

Once this is done, the rating along a single PAD dimension that a subject will attribute to gaze shifts generated through the composition of these individual gaze behaviors can be predicted. For example, a gaze shift containing more behaviors associated with a higher mean Dominance rating will be much more likely to be viewed as a High Dominance gaze shift (see Figures 5-1 through 5-5).

In addition, this study demonstrates that limited composition across PAD dimensions is possible, as shown in Table 5-10. This table shows that the emotional categories of Contempt, Excitement, Guilt, and Sadness are significantly related to the same behavior combinations that are also significantly related to the location of the categorical emotion when mapped into PAD space (based on [Jiang, 2007] and [Gebhard, 2005]).

For example, Sadness can be mapped into the PAD space as negative Pleasure (-P), negative Arousal (-A), and negative Dominance (-D). In addition, Sadness is significantly more likely to be attributed to gaze shifts with a bowed head, a neutral torso, and a neutral velocity. In Table 5-7, it is shown that bowed head and a neutral torso are significantly associated with negative Dominance and negative Pleasure, and that a bowed head and neutral velocity are not associated with Agitation. Thus, by combining the Low Dominance (-D) and Low Pleasure (-P) behaviors into a gaze shift, and using no high Agitation (-A) behaviors, subjects will attribute the emotional state of Sadness to the resulting gaze shift.

In addition, many of the relationships between behavior and emotion found in this study are consistent with previous research. For example, [Wallbott, 1998] found that shame was associated with a bowed head, similar to these findings for guilt; and [Coulson, 2004] showed that upwards tilted head & neutral torso was associated with disgust, similar to these contempt findings.

Table 5-10: Composition of Behaviors Across PAD Dimensions into Emotional Categories

Emotional Categories	PAD Rating	Significantly Related Behavior Combinations
Contempt	-P-A+D	Head Raised, Torso Neutral, Velocity Neutral +D -P -A
Excitement	+P+A+D	Head Neutral, Torso Bowed, Velocity Fast +P, +D +P, +D +A, +D
Guilt	-P+A-D/ -P-A-D	Head Bowed, Torso Neutral, Velocity Neutral Head Bowed, Torso Neutral, Velocity Slow -D -P -A
Sadness	-P-A-D/ -P+/-A-D	Head Bowed, Torso Neutral, Velocity Fast Head Bowed, Torso Neutral, Velocity Neutral -D -P +/- A

However, several of these findings conflict with earlier research as well. [Coulson, 2004] found that happiness was attributed to head and chest tilted backwards, while this study found that excitement was attributed to a bowed torso and upright head. [Coulson, 2004]'s subjects, however, attributed anger and fear to postures with the torso bowed and the head upright. In addition, [de Meijer, 1989] found that trunk bowing was strongly correlated with negative affect, while an upright trunk was associated with positive affect, which is the reverse of these findings. Finally, this work does not replicate our previous results showing velocity being highly associated with arousal [Lance & Marsella, 2007].

There are, however, several possible explanations for these differences. One explanation for this is that the "bowed" torso movement used in this work is not viewed as a bowed movement per se by the subjects. Instead, it is perhaps viewed as an "approach" behavior, where the character is moving towards an object or another person. For example, [Carney et al., 2005] demonstrated that "leans forward towards other" was perceived as a dominant nonverbal behavior. Another possibility is that the dynamics of these movements changed the perception of the movement when compared to [Coulson, 2004]'s static postures, or [de Meijer, 1989]'s movements.

The lack of agreement with our own prior results [Lance & Marsella, 2007] is somewhat more disconcerting. The problem here is twofold. First, the rating scales used for the Arousal dimension did not perform very well. Second, the differences between the low, medium, and high velocities in the videos used for this experiment were much lower than those used for [Lance & Marsella, 2007]. These factors likely account for the discrepancy.

It should also be pointed out that several strong assumptions were made during the course of this study, and that improved mappings between emotion and behavior may be obtained by relaxing these assumptions. The first assumption is that the mapping between categorical emotions and PAD space is correct. However, it is currently an open question of *how* and even *if* categorical models of emotion can be mapped into dimensional models of emotion such as the PAD model. As such, improved mappings between emotion and behavior could be obtained by utilizing an alternate mapping between categorical emotions and dimensional emotions, or by forgoing a categorical model of emotion entirely.

Another assumption made is that gaze behaviors affect the attribution of emotion independently from each other. In other words, it is assumed that adding any specific behavior to a gaze shift will affect the attribution of emotion to that gaze shift independent of the gaze behaviors the shift is already portraying. Improved emotion/behavior mappings may be obtained by relaxing this assumption and examining how each gaze behavior affects the attribution of emotion to the other gaze behaviors displayed in a gaze shift, as well as for the gaze shift as a whole.

Finally, a rigorously defined set of low-level behaviors used for expressive gaze would be very valuable to this type of research. While a space of gaze behaviors was determined for this study, there are other possible ways to structure this space that may provide better results. As [Pasch & Poppe, 2007] note, there is no agreed-upon physical parameterization for static posture studies, much less the more complex problem of movement during gaze.

Chapter 6 Conclusion

6.1 Discussion/Review

The primary contribution of this research is the Expressive Gaze Model, a model of gaze that displays desired gaze behaviors directed at arbitrary targets. This model is comprised of two components: the Gaze Warping Transformation, a method for displaying desired head and torso behaviors directed at arbitrary targets; and the procedural eye model, which is based on the visual neuroscience literature and uses that literature to integrate the eye movement with the GWT movement. This model is computationally lightweight and is intended for interactive dynamic applications, including virtual reality, gaming, animation, and implementation in Virtual Embodied Characters. In addition, it is likely to generalize beyond gaze behavior. The two constructs that it is based on, Motion Warping [Witkin & Popovic, 1996] and Emotional Transforms [Amaya et al., 1997], were both developed to manipulate general movement, not just gaze.

The EGM is also intended to require a minimal amount of motion capture data. In this vein, the results to an empirical study that explores the relationship between gaze behaviors and emotional state are also provided. The goal of this study is to obtain a set of low-level gaze behaviors annotated with emotional data that are then combined according to the PAD dimensional model of emotion such that the attribution of emotion to the resulting gaze shift displaying the combined behaviors can be predicted. This will allow the generation of a broader array of emotional responses while using a minimal library of GWTs derived from a minimal set of motion capture data.

The contributions of the research are:

- The Expressive Gaze Model: The first model for realizing expressive gaze in interactive virtual characters.
- The EGM is also the first model of animation that blends a neuroscience-based procedural model of animated eye movement with a motion-capture based animation model.
- The model also provides an approach to transforming physical behaviors into emotionally expressive physical behaviors that may generalize beyond gaze.
- Also contributed is a preliminary mapping between composed emotional dimensions and composed low-level gaze behaviors.

6.2 Future Work

There are many possible avenues of future research available for not only further improvement of the Expressive Gaze Model, but also research utilizing the EGM as a test bed.

6.2.1 Improving the Expressive Gaze Model

The most pressing improvement, in terms of expanding the applicability of the EGM, is the movement from offline gaze generation to a real-time system. Currently, the inverse kinematics system requires too much processing time to function in an interactive environment. However, most real-time animated systems include inverse kinematics skeletons [Tolani et al., 2000] that help prevent movement beyond the physical limitations of the body. Thus, implementing the EGM in real time would require two changes. First, use an optimization system to convert the library of Gaze Warping Transformations into the same skeletal formation as that used by the real-time system. Second, convert the GWT into a parameterization that can be applied frame by frame, instead of the current GWT, which is applied at six key frames. This would provide a parameterized model of movement developed from motion capture data.

Next, increasing the complexity of the gaze behavior model is likely to improve the utility of the EGM considerably. When performing this empirical study, the most common complaint received from the coders was about the lack of movement of the areas around the eye. Developing a FACS-like set of expressive gaze behaviors that includes the actual FACS parameters describing the shape of the eyes and eyelids will vastly increase the ability of the EGM to produce emotionally expressive gaze, although it will also increase the complexity of the emotion-behavior mapping problem. Another possible improvement to the behavior model is integration with a saliency/attention model. Currently this model does not actually determine where the character should gaze, only how. Providing an attention model, such as that described in [Itti, 2005], or an alternative model for generating gaze shifts would remedy that.

Another area where the work could be improved is through the addition of physics modeling. The addition of Spacetime constraints [Witkin & Kass, 1988] would allow the use of a physics model to drive the body; and addition of a biomechanics model such as [Liu et al., 2005] or [Neff & Fiume, 2002] would allow the modeling of tension in a humanoid body, allowing another channel for the display of emotion. Integration of the EGM with other aspects of nonverbal behavior is another potential avenue of research. Facial expression, gesture, prosody and other forms of nonverbal behavior also visibly display emotional content. Expanding the EGM to handle these behaviors, or integrating the EGM with existing models of these behaviors would vastly improve the ability of virtual characters to display emotion.

Another potential area for future improvement is the addition of a machine learning system to analyze and model more complex expressive behavior, such as that in [Busso et al., 2005]. The integration of a machine learning component could be used to synchronize gaze shifts generated with the EGM to subtle and complex types of communicative behavior, such as speech-related head movement, or the way in which two to humans affect each other's nonverbal behavior.

6.2.2 Using the Expressive Gaze Model as a Research Test Bed

There are also many areas of nonverbal behavior research that could be explored using the Expressive Gaze Model as a test bed. For example, further exploration of the relationship between gaze behaviors and emotional state would be valuable. In addition, exploration as to the differences between the emotional states attributed to male vs. female models, or detailed vs. abstract models would provide interesting information about the environmental effects on expressive behavior. Other environmental effects to be explored include the camera angle, the presence or absence of additional characters, and the relative size of the model. The EGM could also be used to explore cross-cultural differences in the emotional states attributed to gaze behaviors. By being able to generate culturally appropriate expressive gaze, the EGM would increase its utility in virtual agents implemented for language or cultural training programs, such as [Johnson, 2007].

In addition to increasing the behavior space used in the mapping between gaze shifts & physical behavior, the EGM would benefit from adding affective or communicative abilities beyond emotional state. For example, the personality or mood of the gazing character, their relationship with the gaze target, or the presence or absence of attempts to negotiate, manipulate, or deceive.

6.3 Conclusion

This research addresses the problem of an expressivity gap between interactive virtual humans and pre-rendered virtual characters by providing the Expressive Gaze Model, a model for expressing emotion through gaze in interactive virtual humans. The hope for this model is that it will allow the creation of interactive characters that can flirt, love, hate, or terrify simply through the way in which they look at a user or at each other.

The Expressive Gaze Model is supported here by the development of a preliminary mapping between emotion and behavior. The goal of this mapping is to allow the generation of complex gaze shifts that portray complex emotional states through the composition of simple gaze behaviors that may be much more easily obtained through motion capture or procedural generation.

In addition, information has been provided about possible research directions that would further improve the ability of interactive animated characters to express their affective and cognitive states through their gaze behavior; as well as research directions where the Expressive Gaze Model would be a useful tool for exploring human behavior and the attribution of affect. Moving forward, the intent is to continue this work and continue to make valuable contributions to Virtual Embodied Agents and other related fields.

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Appendix A: Example BVH File Header

```
HIERARCHY
ROOT Hips
{
	OFFSET 0.00 0.00 0.00
	CHANNELS 6 Xposition Yposition Zposition Yrotation Zrotation Xrotation

	JOINT Shoulders
	{
		OFFSET 0.00 0.00 0.00
		CHANNELS 6 Xposition Yposition Zposition Yrotation Zrotation Xrotation

		JOINT Head
		{
			OFFSET 0.00 0.00 0.00
			CHANNELS 6 Xposition Yposition Zposition Yrotation Zrotation Xrotation

			JOINT Eye
			{
				OFFSET 0.00 0.00 0.00
				CHANNELS 3 Yrotation Zrotation Xrotation
				JOINT Blink
				{
					OFFSET 1.00 1.00 1.00
					CHANNELS 1 Zposition
					End Site
					{
						OFFSET 0.00 0.00 0.00
					}
				}
			}
		}
	}
}
MOTION
Frames: 97
Frame Time: 0.016
```

Tab separated data begins here

Appendix B: Example GWT Evaluation Questionnaire

Question 1:

Please watch the videos and answer the following questions (Circle one answer):

In which video does the individual seem more in **control of their situation**?

Video A Video B

In which video does the individual seem more **agitated**?

Video A Video B

For **Video A,** how much do you **agree or disagree** with the following statements:

The individual in the video is **agitated**.

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
1	2	3	4	5

The individual in the video is **in control of their situation**.

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
1	2	3	4	5

The movement in the video is **human-like.**

Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
1	2	3	4	5

Is the movement in the video a motion capture of a human, or computer generated?

(Circle one answer): **Human** **Computer**

Appendix C: Example Online Data Collection Questionnaire

Gaze and Emotion Survey

Please answer the following questions:

Demographic Data

How old are you?

What gender are you?

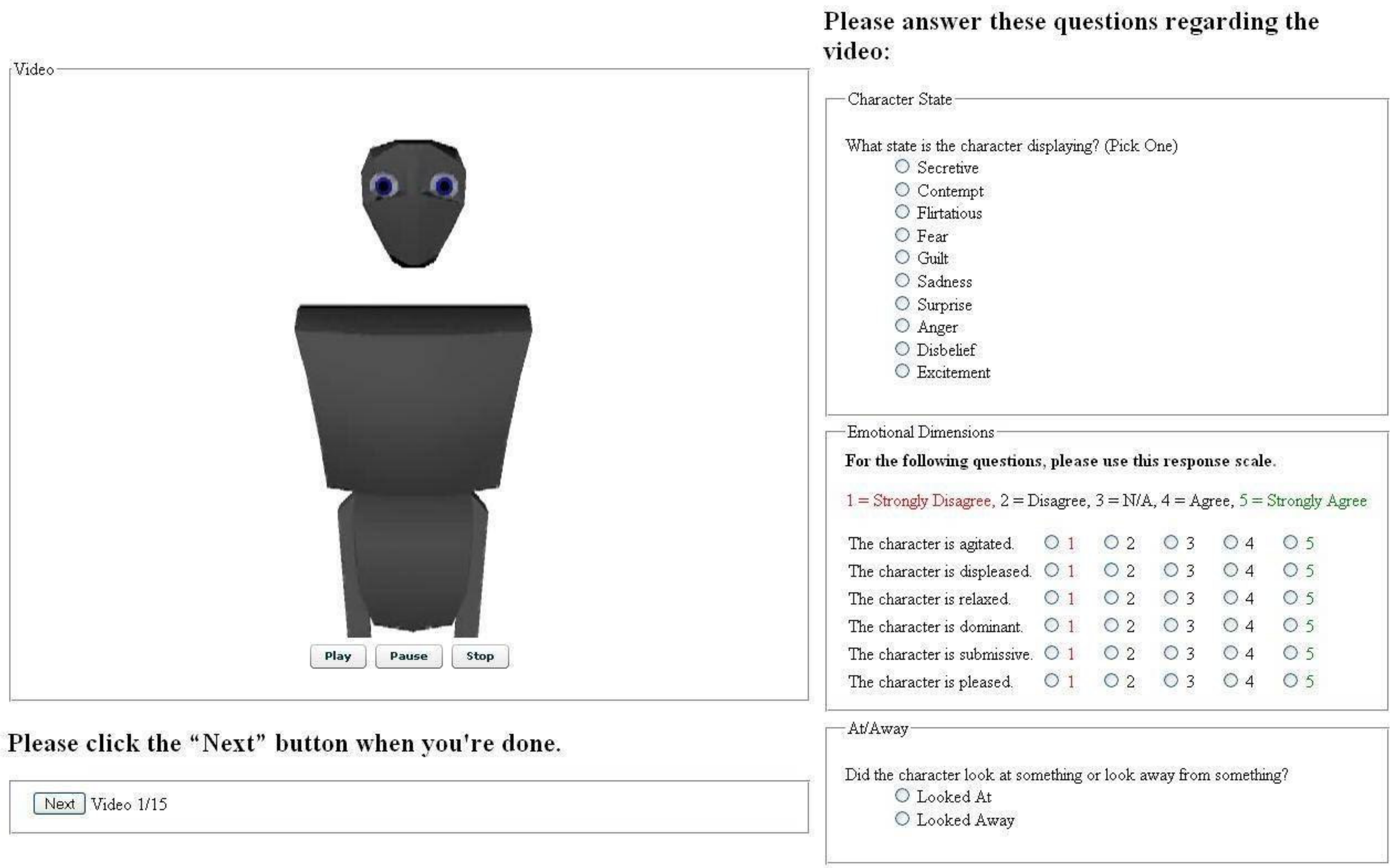
M F

What is your ethnicity?

- American Indian
- Asian
- Black
- Hispanic
- Pacific Islander
- White
- Other

Please click the "Next" button when you're done

Next


Video
Play
Pause
Stop
Please click the "Next" button when you're done.
Next
Video 1/15
Please answer these questions regarding the video:
Character State
What state is the character displaying? (Pick One)
Secretive
Contempt
Flirtatious
Fear
Guilt
Sadness
Surprise
Anger
Disbelief
Excitement
Emotional Dimensions
For the following questions, please use this response scale.
1 = Strongly Disagree, 2 = Disagree, 3 = N/A, 4 = Agree, 5 = Strongly Agree
The character is agitated. 1 2 3 4 5
The character is displeased. 1 2 3 4 5
The character is relaxed. 1 2 3 4 5
The character is dominant. 1 2 3 4 5
The character is submissive. 1 2 3 4 5
The character is pleased. 1 2 3 4 5
At/Away
Did the character look at something or look away from something?
Looked At
Looked Away

Appendix D: The Flock of Birds Motion Tracking System

The coordinate system for the Flock of Birds motion tracking data is measured based on the distance and orientation with regards to a large electromagnet, the FOB transmitter. When collecting the data, the actor stood down the X axis of the FOB transmitter, oriented 90 degrees to the right, so that the transmitter was located laterally to the right of the actor. This meant that the X axis of the transmitter was aligned with the transverse axis of the actor, and increased moving from the actor's right to left, away from the transmitter. The Y axis then corresponded to the sagittal axis of the actor, increasing to the actor's front, and decreasing to the actor's back. Finally, the Z axis measured vertical position, although it decreased when moving upwards, and increased when moving downwards.

The FOB orientation data is measured in Euler angles, also with regards to the FOB transmitter, each describing rotation around one of the three spatial axes. The first angle, γ, describes the sideways yaw rotation of the actor around the Z axis. In order to properly use these angles to drive the animated character, both the rotation matrix for each angle and how the rotation matrices are combined must be known. The matrix transformation for this angle is:

$$\begin{bmatrix} \cos(\gamma) & -\sin(\gamma) & 0 & 0 \\ \sin(\gamma) & \cos(\gamma) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

The second angle, β, describes the forwards and backwards pitch rotation of the actor, and is represented by the matrix transformation:

$$\begin{bmatrix} \cos(\beta) & 0 & \sin(\beta) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\beta) & 0 & \cos(\beta) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

And the third angle, α, represents the roll rotation of the actor around the Y axis, and is represented by the matrix:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The matrix *R*, used to represent the full orientation of the motion sensor is:

$$R = \begin{bmatrix} \cos(\gamma) & -\sin(\gamma) & 0 & 0 \\ \sin(\gamma) & \cos(\gamma) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\beta) & 0 & \sin(\beta) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\beta) & 0 & \cos(\beta) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

And when fully multiplied out becomes:

$$R = \begin{bmatrix} \cos(\beta)\cos(\gamma) & -\cos(\alpha)\sin(\gamma)+\sin(\alpha)\sin(\beta)\cos(\gamma) & \sin(\alpha)\sin(\gamma)+\cos(\alpha)\sin(\beta)\cos(\gamma) & 0 \\ \cos(\beta)\sin(\gamma) & \cos(\alpha)\cos(\gamma)+\sin(\alpha)\sin(\beta)\sin(\gamma) & -\sin(\alpha)\cos(\gamma)+\cos(\alpha)\sin(\beta)\sin(\gamma) & 0 \\ -\sin(\beta) & \sin(\alpha)\cos(\beta) & \cos(\alpha)\cos(\beta) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

The Euler angles can be recovered from the matrix R using the following equations:

$$\begin{aligned} \gamma &= \arctan\left(\frac{R[2][1]}{R[1][1]}\right) \\ \beta &= \arcsin(R[3][1]) \\ \alpha &= \arctan\left(\frac{R[3][2]}{R[3][3]}\right) \end{aligned} \tag{6}$$

Note that this Euler angle system has a singularity located at $\beta = 90°$, causing instability in γ and α as β approaches this value. This information is provided to remove ambiguity due to the existence of several different and commonly-used representations for Euler angles.

Appendix E: The Applied Science Laboratories Eye Tracker System

The Applied Science Laboratories eye tracker is a head-mounted eye tracker that determines eye position by reflecting an infrared illuminator off the back of the eye. This allows the tracker to discern both the pupil and the reflection of the illuminator off of the cornea. The tracker can then determine the orientation of the eye through the difference between the location of the center of the pupil and the location of the corneal reflection. The eye tracker records the horizontal and vertical coordinates of the eye gaze in 2D x/y coordinates.

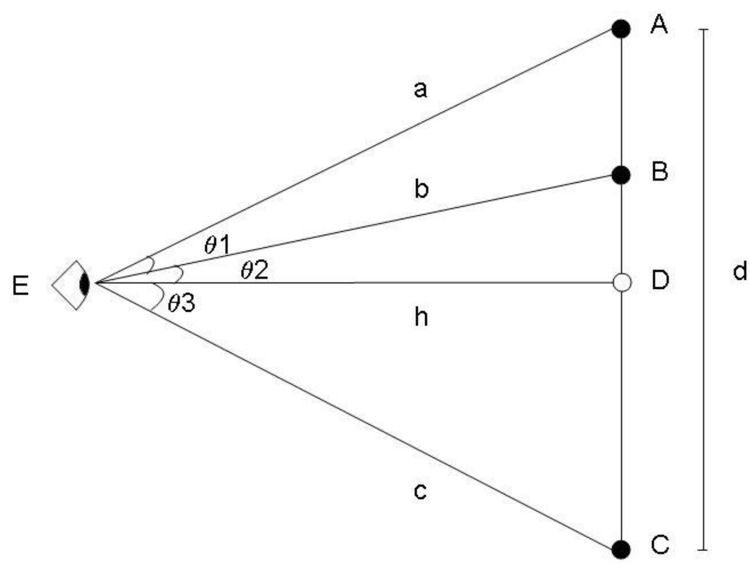


Figure A-1: Geometry for Converting Eye Tracker Units to Degrees

However, as the eye is tracked on a flat 2D plane, these values are recorded in Eye-Tracker Units, and must be converted to standard measurements. In order to convert the gaze coordinates from one dimension into angles the conversion ratio first needs to be calculated. To do this, the actor looks at three points lying on a line in that dimension while holding their head steady. These points are represented by points A, B, and C in Figure A-1. The eye tracker records the coordinates of the actor's gaze, in Eye-Tracker Units, providing the values $e1$, $e2$, and $e3$. The physical distances a, b, c, and d, and the AB and BC segments of d are then measured.

The next step is to calculate $\theta 1$, $\theta 2$, and $\theta 3$ in degrees, and use those values to find the conversion ratio. The height value h, which is perpendicular to segments AB, AC, and BC, is calculated using Heron's formula for the area of a triangle: given sides a, c, and d of a triangle, and semi-perimeter s:

$$s = 1/2(a + c + d) \tag{1}$$

Then, Heron's formula for the area of a triangle A is calculated by:

$$A = \sqrt{s(s-a)(s-c)(s-d)} \tag{2}$$

From which it follows that:

$$A = \frac{dh}{2} \tag{3}$$

$$\frac{dh}{2} = \sqrt{s(s-a)(s-c)(s-d)} \tag{4}$$

$$h = \frac{2}{d}\sqrt{s(s-a)(s-d)(s-c)} \tag{5}$$

The three h values found for the three triangles EAB, EAC, and EBC are then averaged, and the resulting value of h is used to calculate the three angles:

$$\begin{aligned} \theta 1 &= \arccos(\frac{h}{a}) \\ \theta 2 &= \arccos(\frac{h}{b}) \\ \theta 3 &= \arccos(\frac{h}{c}) \end{aligned} \tag{6}$$

Finally, the conversion ratio r between angles and Eye-Tracker Units is calculated through the following formula:

$$r = \frac{1}{3}(\frac{\theta 1}{e1} + \frac{\theta 2}{e2} + \frac{\theta 3}{e3}) \tag{7}$$

After performing this calculation for the vertical and horizontal dimensions, the conversion ratio is then used to obtain the orientation of the eye in angles in regard to a forward-facing camera on the actor's head. While it is possible to automatically integrate the eye tracking and the FOB tracker mounted on the actors head, it is only possible to run one FOB system in a given area at any time. Instead, the eye tracker and motion tracker data are obtained separately, allowing the use of multiple FOB trackers.

Appendix F: Using Optimization for simple Inverse Kinematics

The process used for determining the new neck joint was as follows: first, the distances between the location of the shoulder motion tracker and the Atlas joint at the base of the skull, and between that joint and the location of the head tracker on the actor were both measured. These measurements were converted into matrix transformations, and determined the actual offsets of the new neck bones. The motion tracker data from the lower back is then stored and removed from the data, as it is not relevant to the addition of the new neck joint. The next step was to determine, based on the position and orientation of the shoulder tracker, the position of the new neck joint during each frame of animation. This was done using the following equation:

$$N_p(t) = S_p(t) * S_o(t) * S_N \qquad (1)$$

Where $N_p(t)$ is the transformation matrix position of the neck at every frame, $S_p(t)$ is the transformation for the shoulder position, $S_o(t)$ is the shoulder orientation transformation, and S_N is the translation transformation between the shoulder and the neck positions. The values $S_p(t)$ and $S_o(t)$ are provided by the motion tracker placed between the actor's shoulders, and the S_N translation was found by physically measuring the actor's body. The head data and new neck data are then transformed to neck-local coordinates, so that the new neck joint was located at the origin, and the head location was described in coordinates relative to the neck, using the following equations:

$$N'_p(t) = N_p(t)^{-1} \tag{2}$$

$$H'(t) = N_p(t)^{-1} * H_p(t) * H_o(t) \tag{3}$$

Where $H'(t)$ is the position of the head in neck-local coordinates, and $H_p(t)$ and $H_o(t)$ are the transformation matrices for the position and orientation of the motion tracker placed on the actor's head. The goal of the optimization then becomes to find the angular orientation of the new neck joint $N_o(t)$ that minimizes the equation F:

$$F = \sum_{t=0}^{n} \left(H'(t) - G'_H(t)\right)^2 \tag{4}$$

Where F is the least square difference between the existing head data $H'(t)$, and a new set of head data $G_H(t)$ generated in relation to the neck joint orientation $N_o(t)$ and the translation between the neck joint and the head-mounted motion tracker N_H:

$$G'_H(t) = N_o(t) * N_H \tag{5}$$

The Matlab optimization package then solves for the values of $N_o(t)$ that minimize F across all of the frames of animation simultaneously. However, to do this, the motion capture data must first be recast into three n x 1 vectors *q, m,* and *w*.

All three vectors are n x 1 vectors, where $n = 3 \times t$; 3 is the dimensionality of the data for that sensor, and t is the number of animation frames that the movement takes to perform. The vector q is the initial guess for the neck angle values, and was initialized to zero. The vectors m and w contain the position and orientation data, respectively, for the head in neck-local coordinates. These data vectors and a function that calculates the value of F are then passed to the Matlab package. Matlab returns an n x 1 vector x, which contains the neck angle values $N_o(t)$ that minimize the function *F*. These neck angle values are used to calculate $G'_H(t)$, which replaces $H'(t)$ in the motion capture data. Finally, $G'_H(t)$ is transformed back into global coordinates using the global coordinates of the new neck joint.

$$G_H(t) = G'_H(t) * N_p(t) \tag{6}$$

The resulting movement maintains a strict offset between the shoulders and the new neck joint, and between that neck joint and the head, preventing the head from disconnecting from the torso. It also minimizes the amount of change applied to the head, keeping it as close to the original movement as possible.

Appendix G: The Challenges of Collecting Motion Capture Data

Obtaining the motion data used for this research required several unsuccessful data collection attempts before successfully collecting the data reported here. These unsuccessful attempts are interesting because they indicate the challenges and requirements for successful motion capture of emotional expression.

Our first unsuccessful attempts at collecting emotionally expressive motion capture data involved attempting to induce actual emotion in naïve non-actor human subjects and capturing the resulting behavior. In order to induce emotions, the subjects were first provided with written scenarios, and asked to perform gaze shifts portraying the emotions induced by the scenarios. As this did not provide the emotionally expressive data required, the subjects were then provided with a video interaction intended to induce specific emotional states. However, inducing the correct emotion and then demonstrating through evaluation that the emotion had been induced is an extremely difficult task [Harmon-Jones et al., 2007].

As inducing emotion in naïve subjects proved too difficult, the next approach involved collecting motion data from the portrayal of emotion by actors. However, utilizing actors who portrayed the desired emotion still required trial-and-error experimentation to obtain acceptable data. The actors were first simply asked to portray an emotional state, e.g. "Look at this target while displaying anger." Actors indicated that they found the emotional categories to be too broad to select any individual behavior pattern, and the resulting data demonstrated excessively unnatural and cartoony movements. The actors were then provided with a script, and asked to read and portray a part. However, the resulting data varied based on the words provided to the character, and separating movement that was related to the emphasis and inflection of the speech from that produced by gaze movements proved difficult. For the next attempt, actors were provided the video stimulus, originally used to induce emotion in the naïve subjects. The acors were asked to portray an emotion in reaction to this stimulus. Again, the actors found the space of potential responses too broad to provide specific emotional behavior.

These difficulties lead to the next approach, where realistic behaviors were obtained from two actors interacting while being supervised and instructed by a skilled director. However, each individual interaction contained idiosyncratic behavior performed at an extremely rapid rate. The complexity of this data would require a bottom up data processing method, similar to [Busso et al., 2005]. The possibilities of modeling this type of data are discussed in the future work section in Chapter 6.

The final, successful approach is the highly controlled data collection method reported in this research. Actors were provided specific patterns of behavior, and asked to portray emotions while performing these specific behavior patterns. This approach limited the space of potential responses by the actor to the point where they could successfully portray realistic emotional behavior.

Appendix H: List of Online Data Collection Gaze Shifts

The animations listed below are available upon request.

Video	Att/Avv	Gaze Type	Head	Torso	Velocity
1	Attraction	Eye Only	High	Neutral	Fast
2	Attraction	Eye Only	High	Neutral	Neutral
3	Attraction	Eye Only	High	Neutral	Slow
4	Attraction	Eye Only	Neutral	Neutral	Fast
5	Attraction	Eye Only	Neutral	Neutral	Neutral
6	Attraction	Eye Only	Neutral	Neutral	Slow
7	Attraction	Eye Only	Neutral	Bowed	Fast
8	Attraction	Eye Only	Neutral	Bowed	Neutral
9	Attraction	Eye Only	Neutral	Bowed	Slow
10	Attraction	Eye Only	Bowed	Neutral	Fast
11	Attraction	Eye Only	Bowed	Neutral	Neutral
12	Attraction	Eye Only	Bowed	Neutral	Slow
13	Attraction	Eye Only	Bowed	Bowed	Fast
14	Attraction	Eye Only	Bowed	Bowed	Neutral
15	Attraction	Eye Only	Bowed	Bowed	Slow
16	Attraction	Head Only	High	Neutral	Fast
17	Attraction	Head Only	High	Neutral	Neutral
18	Attraction	Head Only	High	Neutral	Slow
19	Attraction	Head Only	Neutral	Neutral	Fast
20	Attraction	Head Only	Neutral	Neutral	Neutral
21	Attraction	Head Only	Neutral	Neutral	Slow
22	Attraction	Head Only	Neutral	Bowed	Fast
23	Attraction	Head Only	Neutral	Bowed	Neutral
24	Attraction	Head Only	Neutral	Bowed	Slow
25	Attraction	Head Only	Bowed	Neutral	Fast
26	Attraction	Head Only	Bowed	Neutral	Neutral
27	Attraction	Head Only	Bowed	Neutral	Slow
28	Attraction	Head Only	Bowed	Bowed	Fast
29	Attraction	Head Only	Bowed	Bowed	Neutral
30	Attraction	Head Only	Bowed	Bowed	Slow
31	Attraction	Head Body	High	Neutral	Fast
32	Attraction	Head Body	High	Neutral	Neutral
33	Attraction	Head Body	High	Neutral	Slow
34	Attraction	Head Body	Neutral	Neutral	Fast
35	Attraction	Head Body	Neutral	Neutral	Neutral
36	Attraction	Head Body	Neutral	Neutral	Slow
37	Attraction	Head Body	Neutral	Bowed	Fast
38	Attraction	Head Body	Neutral	Bowed	Neutral
39	Attraction	Head Body	Neutral	Bowed	Slow
40	Attraction	Head Body	Bowed	Neutral	Fast
41	Attraction	Head Body	Bowed	Neutral	Neutral

42	Attraction	Head Body	Bowed	Neutral	Slow
43	Attraction	Head Body	Bowed	Bowed	Fast
44	Attraction	Head Body	Bowed	Bowed	Neutral
45	Attraction	Head Body	Bowed	Bowed	Slow
46	Attraction	Eye Head	High	Neutral	Fast
47	Attraction	Eye Head	High	Neutral	Neutral
48	Attraction	Eye Head	High	Neutral	Slow
49	Attraction	Eye Head	Neutral	Neutral	Fast
50	Attraction	Eye Head	Neutral	Neutral	Neutral
51	Attraction	Eye Head	Neutral	Neutral	Slow
52	Attraction	Eye Head	Neutral	Bowed	Fast
53	Attraction	Eye Head	Neutral	Bowed	Neutral
54	Attraction	Eye Head	Neutral	Bowed	Slow
55	Attraction	Eye Head	Bowed	Neutral	Fast
56	Attraction	Eye Head	Bowed	Neutral	Neutral
57	Attraction	Eye Head	Bowed	Neutral	Slow
58	Attraction	Eye Head	Bowed	Bowed	Fast
59	Attraction	Eye Head	Bowed	Bowed	Neutral
60	Attraction	Eye Head	Bowed	Bowed	Slow
61	Attraction	Eye Head Body	High	Neutral	Fast
62	Attraction	Eye Head Body	High	Neutral	Neutral
63	Attraction	Eye Head Body	High	Neutral	Slow
64	Attraction	Eye Head Body	Neutral	Neutral	Fast
65	Attraction	Eye Head Body	Neutral	Neutral	Neutral
66	Attraction	Eye Head Body	Neutral	Neutral	Slow
67	Attraction	Eye Head Body	Neutral	Bowed	Fast
68	Attraction	Eye Head Body	Neutral	Bowed	Neutral
69	Attraction	Eye Head Body	Neutral	Bowed	Slow
70	Attraction	Eye Head Body	Bowed	Neutral	Fast
71	Attraction	Eye Head Body	Bowed	Neutral	Neutral
72	Attraction	Eye Head Body	Bowed	Neutral	Slow
73	Attraction	Eye Head Body	Bowed	Bowed	Fast
74	Attraction	Eye Head Body	Bowed	Bowed	Neutral
75	Attraction	Eye Head Body	Bowed	Bowed	Slow
76	Aversion	Eye Only	High	Neutral	Fast
77	Aversion	Eye Only	High	Neutral	Neutral
78	Aversion	Eye Only	High	Neutral	Slow
79	Aversion	Eye Only	Neutral	Neutral	Fast
80	Aversion	Eye Only	Neutral	Neutral	Neutral
81	Aversion	Eye Only	Neutral	Neutral	Slow
82	Aversion	Eye Only	Neutral	Bowed	Fast
83	Aversion	Eye Only	Neutral	Bowed	Neutral
84	Aversion	Eye Only	Neutral	Bowed	Slow
85	Aversion	Eye Only	Bowed	Neutral	Fast
86	Aversion	Eye Only	Bowed	Neutral	Neutral
87	Aversion	Eye Only	Bowed	Neutral	Slow
88	Aversion	Eye Only	Bowed	Bowed	Fast

89	Aversion	Eye Only	Bowed	Bowed	Neutral
90	Aversion	Eye Only	Bowed	Bowed	Slow
91	Aversion	Head Only	High	Neutral	Fast
92	Aversion	Head Only	High	Neutral	Neutral
93	Aversion	Head Only	High	Neutral	Slow
94	Aversion	Head Only	Neutral	Neutral	Fast
95	Aversion	Head Only	Neutral	Neutral	Neutral
96	Aversion	Head Only	Neutral	Neutral	Slow
97	Aversion	Head Only	Neutral	Bowed	Fast
98	Aversion	Head Only	Neutral	Bowed	Neutral
99	Aversion	Head Only	Neutral	Bowed	Slow
100	Aversion	Head Only	Bowed	Neutral	Fast
101	Aversion	Head Only	Bowed	Neutral	Neutral
102	Aversion	Head Only	Bowed	Neutral	Slow
103	Aversion	Head Only	Bowed	Bowed	Fast
104	Aversion	Head Only	Bowed	Bowed	Neutral
105	Aversion	Head Only	Bowed	Bowed	Slow
106	Aversion	Head Body	High	Neutral	Fast
107	Aversion	Head Body	High	Neutral	Neutral
108	Aversion	Head Body	High	Neutral	Slow
109	Aversion	Head Body	Neutral	Neutral	Fast
110	Aversion	Head Body	Neutral	Neutral	Neutral
111	Aversion	Head Body	Neutral	Neutral	Slow
112	Aversion	Head Body	Neutral	Bowed	Fast
113	Aversion	Head Body	Neutral	Bowed	Neutral
114	Aversion	Head Body	Neutral	Bowed	Slow
115	Aversion	Head Body	Bowed	Neutral	Fast
116	Aversion	Head Body	Bowed	Neutral	Neutral
117	Aversion	Head Body	Bowed	Neutral	Slow
118	Aversion	Head Body	Bowed	Bowed	Fast
119	Aversion	Head Body	Bowed	Bowed	Neutral
120	Aversion	Head Body	Bowed	Bowed	Slow
121	Aversion	Eye Head	High	Neutral	Fast
122	Aversion	Eye Head	High	Neutral	Neutral
123	Aversion	Eye Head	High	Neutral	Slow
124	Aversion	Eye Head	Neutral	Neutral	Fast
125	Aversion	Eye Head	Neutral	Neutral	Neutral
126	Aversion	Eye Head	Neutral	Neutral	Slow
127	Aversion	Eye Head	Neutral	Bowed	Fast
128	Aversion	Eye Head	Neutral	Bowed	Neutral
129	Aversion	Eye Head	Neutral	Bowed	Slow
130	Aversion	Eye Head	Bowed	Neutral	Fast
131	Aversion	Eye Head	Bowed	Neutral	Neutral
132	Aversion	Eye Head	Bowed	Neutral	Slow
133	Aversion	Eye Head	Bowed	Bowed	Fast
134	Aversion	Eye Head	Bowed	Bowed	Neutral
135	Aversion	Eye Head	Bowed	Bowed	Slow

136	Aversion	Eye Head Body	High	Neutral	Fast
137	Aversion	Eye Head Body	High	Neutral	Neutral
138	Aversion	Eye Head Body	High	Neutral	Slow
139	Aversion	Eye Head Body	Neutral	Neutral	Fast
140	Aversion	Eye Head Body	Neutral	Neutral	Neutral
141	Aversion	Eye Head Body	Neutral	Neutral	Slow
142	Aversion	Eye Head Body	Neutral	Bowed	Fast
143	Aversion	Eye Head Body	Neutral	Bowed	Neutral
144	Aversion	Eye Head Body	Neutral	Bowed	Slow
145	Aversion	Eye Head Body	Bowed	Neutral	Fast
146	Aversion	Eye Head Body	Bowed	Neutral	Neutral
147	Aversion	Eye Head Body	Bowed	Neutral	Slow
148	Aversion	Eye Head Body	Bowed	Bowed	Fast
149	Aversion	Eye Head Body	Bowed	Bowed	Neutral
150	Aversion	Eye Head Body	Bowed	Bowed	Slow

Appendix I: Data from Open-Response Collection

Video	Evaluation
001	expression of comtempt
001	disgust
001	confident
001	The character is either following its distraction as it moves or fixates on a new distraction
001	looking over my shoulder
002	Now I understand. Something that I was aware of, perhaps peripherally, is now clear
002	distrust
002	fear
002	saw a really tall person
002	he's listening to me talk and is not sure that he agrees with me
003	The way the character tilts the head backwards while maintaining eye contact suggests that it is being arrogant.
003	i think i don't like it
003	terrified
003	i'm not sure i trust you but i'm going to pretend to
004	feeling scared
004	confused
004	what?
004	checking for my emotions
005	attention attrackted by something
005	wariness
005	startled
006	focus change without change in social stance
006	interesting
006	uptight, uncomfortable
006	fear
007	feeling forced
007	take a close look
007	interest
007	did you see that?
007	I'm sorry, I was totally distracted, what did you say?
008	interesting
008	wanting to know more
008	Paying close attention to something (as if to listen on something)
008	normal
009	he's trying to see if he recognizes me... He's scritunizing me
009	Secretive.
009	very afraid and careful
009	curious
010	feel guity
010	shame
010	Ashamed

010	ashamed
011	shame
011	shame or contrition
011	shy
011	bashful
012	sad
012	feeling sad
012	feel guilty
012	slowly absorbing what is being said
013	interesting
013	fascination
013	hyper, challenging
013	wants me to repeat what I just said
014	incredulity at what was said
014	confiding
014	trying to make point emphatically
014	i don't believe you
015	he did something bad and he's afraid he'll get caught
015	The character is thoughtful, leaning forward slowly as if pondering a problem.
015	disappointment or disapproval
015	They think I'm saying something interesting, yet a little threatening. They're leaning tforward to hear what I have to say.
016	skepticism or disdain
016	Disgusted by something.
016	repulsed
016	the character is examing something not in their immediate field of view. This time turning its head more quickly not to be noticed, perhaps because the object its focused on turned to notice the character
017	wary
017	The character may be suspicious of something or not wanting to be noticed while looking at something
017	doubt
017	scared
017	wary or nervous of whatever is next to me
018	Following an object or imagining something
018	overwhelmed
018	suspiciously looking in an overacting way
018	This appears to be the same animation as the first, just slightly slower. Same examination applies
018	checking out what is going on to the right
019	scared
019	somewhat shameful
019	The character attempts to direct itself at the target in front of it but remains fixated on a distraction
019	worried
020	feeling not sure

020	Feeling wary of something or someone
020	no idea
020	suspicion
021	distracted
021	distracted
021	distracted
021	attention
022	Paying close attention
022	dude, over there!
022	gawking
022	surrprise
023	interested
023	desire to tell a secret
023	unknown
023	They're listening to me, but are watching something interestig happening behind me.
024	wondering
024	apprehension
024	worried
024	trying to convey a secret.
025	disagrees
025	Character feels sorry for having done something naughty.
025	shy,
025	shame
026	shame
026	Shy, as if to receive a reprimand.
026	check that out
026	defensive
027	embarrassing
027	concern
027	wonder
028	quick verification of something
028	i didnt hear you
028	gossiping
028	character is awaiting some response from me concerning an interesting event occurring off to the side
029	What is it, again?
029	intimidated
029	Completely distracted the character attempts to put emphasis that it remains focused on the target but clearly is not. "Yes, yes! I'm listening (ok.. maybe not)"
029	
030	he did something bad and he's afraid he'll get caught
030	puzzlement
030	trying to decide if it agrees
030	unsure agreement
031	worried
031	disbelieving something

031	self-righteous disapproval
031	hmpf, I'm not so sure
032	trying to fucus
032	Character expresses displeasure with something by arrogantly tossing head back.
032	wary/unknown
032	doesn't convey much at all to me, perhaps the thing which is causing the change of attention is seen as a nuisance
033	he is following some object (like a bird flying in the distance)
033	distraction or stealth vs 3rd party
033	Turned off or disgusted by what someone to his right is saying.
033	do not quite believe what they heard (apprehension maybe)
034	turns back on someone
034	the character is thinking it would like its body language to say they want to disengage from current conversation
034	growing disinterested
034	no
035	sad, mild shock
035	concerned, possibly threatening, ominous
035	continuing a conversation after watching a car crash, interest lies elsewhere
035	somewhat interested
036	trying to be inconspicuos about shifting its body
036	distracted
036	The character turns back towards a target but remains distracted by something else
036	I don't know
037	He wants to urgently say something to me about what is happening behind me.
037	watching a horse (or car) race exitedly otherwise intrusive
037	surprised
037	curosity
038	thinking i can do this
038	it needs to lean closer to the window to get a proper look to its left
038	look at that!
038	mild attention
039	character is observing and tracking the movement of some interesting object
039	distracted
039	interested in something far away
039	following an object with interest
040	he is being sorry about something
040	the character observes something he shouldn't but can't help from looking
040	ashamed
040	guilty
040	deferring to someone with superior status
041	no idea
041	understanding

041	shame
041	nooooo, serious? with a sort of glee satisfaction (like dirty, saucy, spicy gossip on neighbour)
042	guilty
042	thinking it wasn't me
042	very embarrassing
042	beginning to not comprehend
043	Character politely bows for some respected person.
043	want to know but also embarrass
043	suspicious
043	intimidated
044	Character bows for someone important standing some distance away.
044	checking out what is going on to the right
044	sneaky./guilty
044	listening
045	feeling curisous
045	feeling bad about something
045	stealthy comment
045	Feeling angry
046	interested
046	indignant, annoyed
046	someone has just said something interesting so there is a refocus of attention - though the item of interest may need further ellucidation
046	surprise
046	something above my head got his attention
047	take back, subtle surprise or disbelief
047	threatened and trying to save face
047	surprised
047	unknown
048	something caught his attention
048	Imagining something
048	disappointed
048	The character realizes that the target it was conversing with may have realize its distraction and so turns it head back to focus itself on the target
048	worried about what is on the right and checking in with me
049	Responding to something that's been said
049	surprised , probably on hearing an unexpected sound.
049	gaze at
050	Character changes his attention to me. As if I said something, or he's about to say something.
050	interested by something straight ahead, must redirect gaze
050	curious, inquisitve, apprehensive
050	curiosity
050	I have his attention...pretty neutral
051	when you see a friend
051	re-engaging

051	alertness
051	Character realizing it was distracted slowly regains focus on the main target
051	checking out something unusual
052	very interested
052	Super interested
052	shock
052	almost seems angry at me, picking a fight
053	explanation
053	'something in front of me is very interesting'
053	All of his attention is on me. He in genuinely interested.
053	yeesss..... YOU!
054	interested
054	unknown
054	he/it is very interested in something I just said or am hinting about
054	The character follows the distraction as it moves behind the target
055	he is scolding someone
055	scolding
055	and you?
055	shame
056	curious contemplation
056	obidient
056	looking for agreement
056	shy
057	polite intimidation / persuasion
057	what have we here?, probing, questioning, almost accusing
057	disbelief
057	dissappointed
057	
058	argue
058	character is impatiently awaiting some response from me
058	surprised
058	anger
059	bowing
059	confused, requesting more information
059	understanding
059	Well hello there! Looking over one's glasses down at a child or other underling.
060	over-bearing intimidation / persuasion
060	Character politely bows/leans forward as if to speak to me.
060	suspicious
060	shocked
061	pride
061	arrogance
061	thinking yes i did something wrong
061	oh, hello
062	everything will be okay

062	happy greeting
062	superiority
062	neutral
063	when you see somebody you don't like
063	i think i am better than you
063	interest or greeting
063	Thinking about something that's been said
064	something had caught his attention but he came back to what he was paying attention to
064	concentration
064	switching from one conversational partner to another
064	momentarily distracted, now focusing on me
065	returning to social context from prior distraction
065	paying attention
065	Neutral.
065	interest
066	cautious
066	Surprise, dread, something bad has happened
066	just noticed you and then recognized you
066	predatory
067	confrontational
067	Paying close attention to something
067	interest
067	what do you want? change attention to interruption, but with a dominant posture toward it
068	curiousity
068	Paying close attention to something
068	sharing some interesting news
068	scared
069	interest or aggression
069	the character is engaged in something else but i've drawn him into a conversation by saying/doing something interesting
069	they just heard something that surprised them
069	curious
070	aggression
070	feeling sad at itself, probably some one scolded him.
070	ashamed or guilty
070	sad
071	obedience
071	ashamed
071	sees something on the ground??
071	Feeling ashamed
072	he is being punished by someone
072	overbearing do it now
072	feeling sad , remorseful
072	feeling reproached by something I said
073	doubting

073	the guy is trying to provoke me
073	stomach illness
073	don't you feel the same way
074	the guy is trying to intimidate me
074	feeling condescending as if they were talking/looking at a child/younger person
074	character is awaiting or trying to illicit some response from me
074	reprimanding
075	over bearing intimidation / persuasion
075	thinking it should adopt the "detective look" i.e. I know you're guilty of something
075	overbearing
075	shocked
076	interest in something beyond the immediate social context
076	he is curious about something
076	saw something interesting
076	Avoiding something
077	Character turns head to look at something interesting but has to look over some obstacle in order to get a view, hence tilts head back.
077	while currently engaged in a conversation/dialog, some interesting event is going on elsewhere
077	upset
077	it wants me to check out something far away it finds interesting
078	fear
078	Surprise, but a positive one. An old friend enters the frame of reference takes a while to recognize, then deep contentment is generated
078	Character is quickly distracted by something outside the normal field of view and out of curiosoity continues to examine the oddity
078	hesitation
079	something caught his attention
079	nervous
079	distracted
079	The character is distracted by something, attempts to regain focus but ultimately fails and continues being distracted
080	The character sees something interesting.
080	confusion
080	Scared, frozen
080	agreement
081	something caught his attention
081	bored
081	The character is quickly distracted and remains fixated on the distraction
081	nervousness
082	take a look
082	afraid
082	paying attention to something else, while pretending to pay attention to me

082	did you see that?
083	curiosity
083	want to know what 's going on
083	conspiratorial
083	careful
084	curious about something but afraid to find out
084	distracted
084	character is trying to observe some object without being detected
084	afraid, careful
085	The character is shy, as if anticipating something embarassing. Or looking at an interesting member of the opposite sex.
085	Well, am I right?
085	he's trying to be cute and adorable
085	shame
086	thinking
086	I'm sorry!
086	contrition
086	Yes my liege. Subservient, but resenting it a bit
087	hesitant eyecontact, fear, cowering
087	feeling admonished
087	Ashamed
087	The character appears to have been noticed by someone and is embarrassed
088	curious
088	guilty
088	he's about to tell me a secret about something and doesn't want to be heard
088	anger
089	leaning in to tell a secret
089	he is questioning someone while being skeptic
089	want to know what 's going on
089	I have my eye on you. You are not in trouble (yet) but I will catch you when you screw up
090	leaning in to tell a secret about the object being looked at
090	is there something over there
090	stealthy, disapproval of 3rd party
090	Being wary or something or angry at something
091	objecting somebody's opinion and behaving like a hypocrat
091	sulking
091	upset, in a huff
091	offended
092	I've seen all I want to see, and I'm making up my mind, and it's not going to be good
092	
092	disaprove, attitude
092	angry at me
092	he's undecided about something I said
093	he is skeptic about something

093	upset
093	skepticism
093	Imagining something or ignoring something
094	Something moves quickly in the character's field of view, causing a sudden change of attention.
094	No. I don't like it
094	some one hearing something they do not want to believe
094	can't tell
095	he is following someone's movement
095	mild interest
095	scared
095	I don't know
095	distracted
096	mild distaste/disapproval/skepticism
096	Amused, entranced, can't take my eyes off this beautiful or bewitching site
096	uncertainty
096	it does not want to look away, maybe scared
097	Really? extreme interest
097	trying to sell me something
097	dude, wtf?!
097	checking for agreement
098	thinking i know you see me looking at you
098	want to join the conversation
098	attentive
098	what did you say?
099	cautious doubt
099	feeling like its missing something to the left of him
099	Curious
099	caring
100	bashful
100	aww, cute little puppy
100	The character is shyed or embarrassed by something the target has said or done
100	slightly disappointed
101	shy
101	The character is once again embarrased or shyed by the target in front of it
101	shy
102	shy, subservient, coy, possibly embarrassed
102	girl trying to be cute and lovey dovey
102	showing sadness in an overacting kind of way
102	uncertainty over my feelings
103	uncertainty about what he heard
103	what did you say
103	interested, but skeptical
103	forcing their hand, trying to make you do what they want
104	asking for confirmation about a secret or something

104	don't you think? Nudge nudge wink wink
104	curious
104	curiosity
105	what did you say
105	Disbelief.
105	whispering a secret
105	challenging
106	not satisfy
106	are you kidding me?
106	Doesn't believe me or turned off in what I'm saying.
106	stand offish
107	mild apprehension/incredulity
107	rejection
107	angry with someone
107	
108	extreme disbelief
108	humoring the speaker
108	looking at a project catapulted into the air
108	somewhat angry at me
108	getting angry with me
109	disbelief or distrust while maintain social context
109	feeling confident
109	Coy, nervous, ill at ease, trying to hide a bit
109	a desire to disengage from the current conversation
110	wants to divide attention between something to its left and something in front of it
110	yeah, righhhhtttt....
110	reverent
110	not sure, maybe skeptical?
110	The character opens its posture because its not really interesting in the target in front of it... the character might be listening to something else or about to look away somewhere else in distraction
111	normal mood
111	confused
111	Character subtly turns attention in another direction, as if to end a conversation.
111	afraid
112	trying to be convincing
112	inquiring in a manicing way
112	curious
112	interested to learn more about what I'm talking about
113	interest
113	Character is trying to get closer to something either because it is intruiged or can't hear what the target is saying/doing
113	uncertainity
113	trying to overhear someone
113	interest
114	The character leans forward as if to examine something or speak

	hushed about something private.
114	surprise and curiousity
114	intimacy
114	He is very intrested in what I have to say.
115	shame
115	stong disagreement
115	feeling shy
115	coquettish
116	The character is flirting.
116	embarrassing
116	Well, am i right?
116	lots of flirting!!!
117	cowering, partially leaving social context
117	ashamed
117	embarrassment
117	sadness or feeling shy
117	flirting
118	don't know
118	let me get closer!
118	The character is about to become privy to some piece of information - possibly gossip or something of an illicit nature
118	attentive
119	checking the answer on a piece of paper
119	Feeling ashamed or listening to something
119	curious
119	curosity
120	shall i tell you a secret
120	gossip
120	liking
120	sad
121	surprise at a distant event
121	what's happening there?
121	Ive had enough of the conversation
121	over there, looking over something high, like a hedge
121	The character's attention is grabbed and is looking over in curiosity
122	he is looking for something
122	heard a noise
122	Ignoring something
122	go away
123	holier than thou righteousness
123	surprise at the distant event
123	surprised, intrigued, mostly positive affect toward the impulse
123	interest
124	fully attentional about something
124	i see something over there
124	something got his attention to my right
124	look away, mad

125	The character sees something interesting that moves.
125	disinterested
125	upset
125	change of interest
126	trasing something interesting
126	shifting attention
126	something out of the ordinary
126	distracted
127	excited
127	hey, what's happening? intense curiosity, almost reckless
127	excited
127	listening
128	curiosity
128	apprehensive
128	Craning nect a bit to see something, but still a little hesitant, not a celebrity but just a bird
128	heavy interest
129	interest
129	thinking i caught you
129	really want to know what 's going on
129	Peeping at something
130	cowering or surprise with disbelief at an unexpected event
130	skepticism or mild disapproval
130	incredulity
130	attraction
131	shame
131	a bit shy
131	subservient, demure, shy
131	'look over that way - there's something going on over there that i don't like or approve of'
132	sorry for doing something wrong
132	Ashamed and submssive.
132	disbelief
132	wants to check something out
133	want to know what 's going on (quickly respond)
133	Interested and threatened
133	attentive
133	shock, surprise
134	somebody told him something and he verifies whether it is correct, like look through the window and see if really there is a person crossing
134	thinking it needs to lean closer to get a better look, inquisitive
134	interest
134	character is again indicating that i should look to the side
135	he is sorry something he did is causing trouble
135	just take a look
135	feeling very intrigued by something
135	caution/condecsension

136	looking over another object
136	shock
136	sarcasm
136	interest/aloofness
137	Imagining or ignoring something
137	mild interest of some event
137	pride
137	something else got his attention
138	Character sees something interesting that is moving, e.g. a car or an aircraft.
138	scared
138	the character is observing some interesting scene as it unfolds
138	discovered something and disaprove it
139	upset
139	shift in attention
139	distracted
139	shock
140	scared of having done something wrong
140	dont believe what it saw
140	upset
140	distraction or deep thought
141	trying to act nonchalant, suspicious
141	surprised by something that suddently happens to its left
141	fear
141	scared
142	Reacting to a sudden sound or motion
142	the character thinks i have something very secretive to tell him
142	heavy interest
142	attentive
143	he is looking out to get a better view
143	talk a better look
143	Peeping at something
143	afraid
144	thinking dont move over there
144	Something new has caught the character's interest, and he/she/it is leaning forward to take a closer look.
144	what to know what 's going on (dangerous event)
144	take a look
145	cowering while trying to avoid leaving the social context
145	feeling shock
145	Character feels sorry for having done something naughty.
145	embarrassing
145	coy, flirting, as before
146	shame
146	coy, flirting
146	looking at someone saying something like "really?...".
146	scared of whatever is next to me

147	surprise at the sudden arrival
147	scorn
147	They just noticed someone they're afraid of or intimidated by come up to them.
147	seeing someone you know is dominant over you
148	giving explanation
148	say what?
148	imparting scandalous information
148	character is indicating to me that i should look in the same vicinity as the character is looking
149	Something interesting, but also a bit disappointing. The item isn't favorable. The character isn't threatened, but isn't attacking either
149	cannot tell maybe they are deaf and could not hear
149	disbelief
149	curiosity
150	half ashamed
150	conspiring
150	checking out what is going on to the right

Appendix J: Neutral Gaze Shift GWTs

Each GWT consists of six keyframes covering 18 degrees of freedom. The degrees of freedom are: X, Y, Z, Roll, Pitch, and Yaw; for each of the three sensors – head, shoulders, and lower back. The first term in each element of the GWT is the time scaling parameter, which will scale the time at which the keyframe will occur. The second term in each element is the curve displacement parameter, which will modify the actual values of the curve. These GWTs are used to produce emotionally neutral gaze shifts, by applying them to a stationary gaze "shift." The up and left gaze shifts can be generated by inverting the down and right GWTs, respectively.

Down 10 Degrees

1,0.000	0.100,0.020	0.275,-0.025	0.425,-0.065	0.325,-0.120	0.295,-0.150
1,0.000	0.100,-0.040	0.275,-0.115	0.425,0.145	0.325,0.140	0.295,0.060
1,0.000	0.100,0.040	0.275,-0.005	0.425,-0.120	0.325,-0.125	0.295,-0.105
1,0.000	0.100,0.160	0.275,0.610	0.425,0.225	0.325,0.360	0.295,0.330
1,0.000	0.100,0.040	0.275,-1.050	0.425,-7.850	0.325,-9.370	0.295,-9.270
1,0.000	0.100,-0.120	0.275,-0.040	0.425,-0.775	0.325,-0.460	0.295,-0.340
1,0.000	0.100,0.015	0.275,-0.025	0.425,-0.065	0.325,-0.085	0.295,-0.085
1,0.000	0.100,-0.040	0.275,-0.060	0.425,-0.230	0.325,-0.360	0.295,-0.450
1,0.000	0.100,-0.020	0.275,0.020	0.425,0.045	0.325,0.090	0.295,0.110
1,0.000	0.100,-0.020	0.275,0.170	0.425,0.205	0.325,0.120	0.295,-0.040
1,0.000	0.100,0.005	0.275,0.180	0.425,0.650	0.325,0.920	0.295,1.055
1,0.000	0.100,0.050	0.275,-0.050	0.425,-0.010	0.325,-0.020	0.295,0.080
1,0.000	0.100,-0.030	0.275,-0.045	0.425,-0.115	0.325,-0.110	0.295,-0.130
1,0.000	0.100,-0.025	0.275,-0.080	0.425,-0.170	0.325,-0.200	0.295,-0.250
1,0.000	0.100,0.005	0.275,0.020	0.425,0.030	0.325,0.020	0.295,0.015
1,0.000	0.100,0.050	0.275,-0.020	0.425,-0.150	0.325,-0.130	0.295,-0.160
1,0.000	0.100,0.000	0.275,0.035	0.425,0.250	0.325,0.420	0.295,0.580
1,0.000	0.100,-0.095	0.275,-0.145	0.425,-0.215	0.325,-0.055	0.295,0.035

Down 23 Degrees

1,0.000	0.650,0.080	1,0.050	1.450,-0.225	0.750,-0.350	0.591,-0.390
1,0.000	0.650,-0.145	1,0.045	1.450,1.515	0.750,1.815	0.591,1.750
1,0.000	0.650,0.025	1,-0.015	1.450,0.070	0.750,0.145	0.591,0.165
1,0.000	0.650,0.000	1,0.210	1.450,1.035	0.750,1.180	0.591,1.050
1,0.000	0.650,0.120	1,-2.685	1.450,-18.970	0.750,-22.740	0.591,-22.930
1,0.000	0.650,-0.150	1,0.020	1.450,0.085	0.750,0.310	0.591,0.360
1,0.000	0.650,0.035	1,0.045	1.450,-0.025	0.750,-0.085	0.591,-0.105
1,0.000	0.650,-0.120	1,-0.180	1.450,-0.170	0.750,-0.220	0.591,-0.300
1,0.000	0.650,-0.020	1,0.040	1.450,0.045	0.750,0.065	0.591,0.080
1,0.000	0.650,0.010	1,0.150	1.450,-0.035	0.750,-0.240	0.591,-0.390
1,0.000	0.650,0.110	1,0.460	1.450,0.370	0.750,0.240	0.591,0.335
1,0.000	0.650,0.120	1,0.070	1.450,0.240	0.750,0.380	0.591,0.530
1,0.000	0.650,-0.020	1,-0.015	1.450,-0.055	0.750,-0.045	0.591,-0.070
1,0.000	0.650,-0.070	1,-0.140	1.450,-0.110	0.750,-0.070	0.591,-0.110
1,0.000	0.650,-0.015	1,0.010	1.450,0.030	0.750,0.015	0.591,0.005
1,0.000	0.650,-0.010	1,-0.160	1.450,-0.030	0.750,0.000	0.591,-0.160
1,0.000	0.650,0.020	1,0.090	1.450,0.420	0.750,0.500	0.591,0.600
1,0.000	0.650,-0.055	1,-0.215	1.450,-0.135	0.750,0.075	0.591,0.185

Down 34 Degrees

1,0.000	0.450,-0.095	1.100,-0.370	1.700,-0.605	0.800,-0.740	0.591,-0.690
1,0.000	0.450,-0.135	1.100,-0.110	1.700,1.915	0.800,2.270	0.591,2.200
1,0.000	0.450,0.060	1.100,0.055	1.700,0.250	0.800,0.425	0.591,0.425
1,0.000	0.450,0.040	1.100,1.080	1.700,1.345	0.800,1.260	0.591,0.890
1,0.000	0.450,-0.160	1.100,-3.600	1.700,-27.610	0.800,-32.990	0.591,-33.220
1,0.000	0.450,0.285	1.100,1.350	1.700,0.505	0.800,0.570	0.591,0.360
1,0.000	0.450,0.025	1.100,-0.115	1.700,-0.195	0.800,-0.285	0.591,-0.315
1,0.000	0.450,-0.125	1.100,-0.315	1.700,-0.350	0.800,-0.510	0.591,-0.640
1,0.000	0.450,-0.020	1.100,0.010	1.700,0.085	0.800,0.120	0.591,0.120
1,0.000	0.450,0.115	1.100,0.140	1.700,-0.145	0.800,-0.430	0.591,-0.720
1,0.000	0.450,0.090	1.100,0.150	1.700,0.480	0.800,0.410	0.591,0.445
1,0.000	0.450,0.290	1.100,1.110	1.700,1.620	0.800,1.960	0.591,2.060
1,0.000	0.450,-0.015	1.100,0.005	1.700,0.025	0.800,0.010	0.591,-0.020
1,0.000	0.450,-0.095	1.100,-0.305	1.700,-0.170	0.800,-0.130	0.591,-0.200
1,0.000	0.450,0.010	1.100,0.035	1.700,0.100	0.800,0.090	0.591,0.095
1,0.000	0.450,0.320	1.100,0.230	1.700,0.230	0.800,0.050	0.591,-0.160
1,0.000	0.450,0.200	1.100,0.410	1.700,1.350	0.800,1.590	0.591,1.660
1,0.000	0.450,-0.080	1.100,0.075	1.700,0.285	0.800,0.465	0.591,0.515

Down 43 Degrees

1,0.000	1.075,0.000	0.525,-0.090	1.025,-0.315	0.775,-0.550	0.432,-0.570
1,0.000	1.075,-0.040	0.525,0.730	1.025,3.785	0.775,4.400	0.432,4.320
1,0.000	1.075,0.025	0.525,0.005	1.025,0.830	0.775,1.285	0.432,1.315
1,0.000	1.075,-0.120	0.525,-0.720	1.025,-2.085	0.775,-2.960	0.432,-3.520
1,0.000	1.075,-0.115	0.525,-6.275	1.025,-35.210	0.775,-42.320	0.432,-42.690
1,0.000	1.075,-0.150	0.525,-0.380	1.025,-0.255	0.775,0.750	0.432,0.650
1,0.000	1.075,-0.025	0.525,-0.055	1.025,-0.025	0.775,-0.105	0.432,-0.175
1,0.000	1.075,-0.090	0.525,-0.080	1.025,-0.160	0.775,-0.280	0.432,-0.440
1,0.000	1.075,-0.020	0.525,0.000	1.025,-0.330	0.775,-0.630	0.432,-0.650
1,0.000	1.075,-0.080	0.525,0.000	1.025,0.605	0.775,0.870	0.432,0.540
1,0.000	1.075,0.070	0.525,-0.075	1.025,-3.855	0.775,-6.670	0.432,-6.745
1,0.000	1.075,0.110	0.525,0.050	1.025,0.820	0.775,1.350	0.432,1.450
1,0.000	1.075,-0.040	0.525,-0.050	1.025,-0.035	0.775,0.030	0.432,0.000
1,0.000	1.075,-0.060	0.525,-0.120	1.025,-0.350	0.775,-0.585	0.432,-0.770
1,0.000	1.075,0.005	0.525,0.010	1.025,0.000	0.775,-0.070	0.432,-0.105
1,0.000	1.075,-0.010	0.525,-0.070	1.025,-0.280	0.775,-0.470	0.432,-0.690
1,0.000	1.075,-0.080	0.525,-0.170	1.025,-0.430	0.775,-0.940	0.432,-1.020
1,0.000	1.075,-0.095	0.525,-0.155	1.025,-0.125	0.775,0.145	0.432,0.345

Right 9 Degrees

1,0.000	0.250,0.030	0.225,0.070	0.800,0.200	0.375,0.170	0.227,0.150
1,0.000	0.250,-0.005	0.225,-0.065	0.800,-0.315	0.375,-0.440	0.227,-0.500
1,0.000	0.250,0.025	0.225,0.015	0.800,0.045	0.375,0.045	0.227,0.065
1,0.000	0.250,0.090	0.225,1.485	0.800,7.425	0.375,8.875	0.227,8.940
1,0.000	0.250,0.050	0.225,0.190	0.800,0.185	0.375,-0.010	0.227,0.020
1,0.000	0.250,-0.100	0.225,0.050	0.800,0.325	0.375,0.880	0.227,0.930
1,0.000	0.250,0.025	0.225,0.020	0.800,0.045	0.375,0.055	0.227,0.075
1,0.000	0.250,0.000	0.225,0.050	0.800,0.125	0.375,0.090	0.227,0.050
1,0.000	0.250,-0.030	0.225,0.005	0.800,-0.015	0.375,-0.000	0.227,0.010
1,0.000	0.250,0.010	0.225,0.060	0.800,0.195	0.375,0.210	0.227,0.180
1,0.000	0.250,-0.040	0.225,0.040	0.800,-0.040	0.375,0.070	0.227,0.185
1,0.000	0.250,0.030	0.225,-0.160	0.800,-0.300	0.375,-0.340	0.227,-0.290
1,0.000	0.250,-0.020	0.225,-0.005	0.800,-0.035	0.375,0.005	0.227,0.000
1,0.000	0.250,-0.010	0.225,-0.030	0.800,-0.010	0.375,0.020	0.227,0.000
1,0.000	0.250,0.005	0.225,0.020	0.800,0.015	0.375,-0.015	0.227,-0.015
1,0.000	0.250,0.030	0.225,-0.010	0.800,-0.000	0.375,0.070	0.227,0.090
1,0.000	0.250,-0.040	0.225,-0.060	0.800,-0.015	0.375,0.000	0.227,0.060
1,0.000	0.250,-0.145	0.225,-0.195	0.800,-0.295	0.375,-0.105	0.227,-0.125

Right 21 Degrees

1,0.000	0.375,0.060	0.350,0.120	1.200,0.530	0.425,0.640	0.409,0.630
1,0.000	0.375,-0.015	0.350,-0.210	1.200,-0.965	0.425,-1.160	0.409,-1.220
1,0.000	0.375,0.035	0.350,0.035	1.200,0.090	0.425,0.085	0.409,0.085
1,0.000	0.375,0.200	0.350,3.490	1.200,17.310	0.425,20.870	0.409,21.190
1,0.000	0.375,-0.040	0.350,-0.290	1.200,-1.200	0.425,-1.610	0.409,-1.620
1,0.000	0.375,-0.135	0.350,0.520	1.200,1.485	0.425,1.690	0.409,1.720

1,0.000	0.375,0.025	0.350,0.035	1.200,0.190	0.425,0.255	0.409,0.295
1,0.000	0.375,-0.045	0.350,-0.030	1.200,-0.080	0.425,-0.140	0.409,-0.190
1,0.000	0.375,-0.020	0.350,0.020	1.200,0.025	0.425,0.030	0.409,0.040
1,0.000	0.375,-0.070	0.350,0.110	1.200,0.495	0.425,0.710	0.409,0.820
1,0.000	0.375,0.050	0.350,0.170	1.200,0.355	0.425,0.430	0.409,0.525
1,0.000	0.375,0.030	0.350,-0.120	1.200,-0.400	0.425,-0.450	0.409,-0.420
1,0.000	0.375,0.010	0.350,0.010	1.200,0.080	0.425,0.125	0.409,0.165
1,0.000	0.375,-0.010	0.350,-0.060	1.200,-0.135	0.425,-0.150	0.409,-0.180
1,0.000	0.375,0.005	0.350,0.030	1.200,0.035	0.425,0.010	0.409,0.015
1,0.000	0.375,0.095	0.350,0.060	1.200,0.180	0.425,0.260	0.409,0.380
1,0.000	0.375,0.100	0.350,0.200	1.200,0.490	0.425,0.600	0.409,0.650
1,0.000	0.375,0.015	0.350,-0.155	1.200,-0.225	0.425,-0.175	0.409,-0.155

Right 35 Degrees

1,0.000	0.375,0.010	0.225,0.180	0.825,1.035	0.375,1.260	0.341,1.290
1,0.000	0.375,-0.055	0.225,-0.435	0.825,-1.645	0.375,-1.960	0.341,-2.055
1,0.000	0.375,0.035	0.225,0.005	0.825,0.100	0.375,0.075	0.341,0.085
1,0.000	0.375,0.330	0.225,5.255	0.825,28.395	0.375,34.700	0.341,35.380
1,0.000	0.375,0.070	0.225,0.240	0.825,-0.330	0.375,-1.100	0.341,-1.145
1,0.000	0.375,-0.060	0.225,-0.425	0.825,0.765	0.375,1.030	0.341,0.970
1,0.000	0.375,0.005	0.225,-0.025	0.825,0.115	0.375,0.195	0.341,0.255
1,0.000	0.375,-0.020	0.225,-0.000	0.825,-0.060	0.375,-0.140	0.341,-0.220
1,0.000	0.375,-0.010	0.225,0.020	0.825,0.005	0.375,0.020	0.341,0.050
1,0.000	0.375,-0.050	0.225,0.010	0.825,0.385	0.375,0.530	0.341,0.565
1,0.000	0.375,0.040	0.225,0.170	0.825,0.420	0.375,0.570	0.341,0.715
1,0.000	0.375,0.070	0.225,-0.000	0.825,-0.400	0.375,-0.480	0.341,-0.520
1,0.000	0.375,-0.030	0.225,-0.045	0.825,-0.075	0.375,-0.010	0.341,0.030
1,0.000	0.375,0.010	0.225,-0.020	0.825,-0.060	0.375,-0.080	0.341,-0.125
1,0.000	0.375,0.015	0.225,0.030	0.825,0.040	0.375,0.010	0.341,0.005
1,0.000	0.375,0.080	0.225,-0.080	0.825,-0.190	0.375,-0.150	0.341,-0.090
1,0.000	0.375,-0.030	0.225,-0.025	0.825,0.150	0.375,0.220	0.341,0.350
1,0.000	0.375,-0.075	0.225,-0.175	0.825,-0.365	0.375,-0.295	0.341,-0.305

Right 54 Degrees

1,0.000	0.975,0.070	0.300,0.270	0.875,1.440	0.525,1.735	0.273,1.770
1,0.000	0.975,-0.055	0.300,-0.560	0.875,-2.020	0.525,-2.305	0.273,-2.380
1,0.000	0.975,0.025	0.300,0.025	0.875,0.155	0.525,0.175	0.273,0.185
1,0.000	0.975,-0.210	0.300,7.930	0.875,44.895	0.525,53.575	0.273,54.750
1,0.000	0.975,0.050	0.300,-0.470	0.875,-1.140	0.525,-1.730	0.273,-1.810
1,0.000	0.975,-0.260	0.300,-0.090	0.875,1.235	0.525,1.150	0.273,0.890
1,0.000	0.975,0.025	0.300,-0.005	0.875,0.005	0.525,0.025	0.273,0.025
1,0.000	0.975,-0.085	0.300,-0.080	0.875,-0.085	0.525,-0.110	0.273,-0.170
1,0.000	0.975,0.000	0.300,0.040	0.875,0.035	0.525,0.040	0.273,0.040
1,0.000	0.975,-0.200	0.300,-0.190	0.875,0.145	0.525,0.510	0.273,0.580
1,0.000	0.975,0.110	0.300,0.260	0.875,0.350	0.525,0.310	0.273,0.315
1,0.000	0.975,0.010	0.300,-0.170	0.875,-0.360	0.525,-0.470	0.273,-0.480
1,0.000	0.975,0.000	0.300,-0.025	0.875,-0.085	0.525,-0.070	0.273,-0.090
1,0.000	0.975,-0.065	0.300,-0.110	0.875,-0.140	0.525,-0.120	0.273,-0.140
1,0.000	0.975,0.015	0.300,0.040	0.875,0.060	0.525,0.030	0.273,0.035
1,0.000	0.975,-0.060	0.300,-0.150	0.875,-0.140	0.525,-0.020	0.273,0.020
1,0.000	0.975,0.070	0.300,0.130	0.875,0.435	0.525,0.600	0.273,0.740
1,0.000	0.975,-0.075	0.300,-0.235	0.875,-0.295	0.525,-0.185	0.273,-0.185

Right 62 Degrees

1,0.000	1.025,-0.120	0.275,0.150	0.900,1.605	0.750,2.180	0.386,2.300
1,0.000	1.025,0.180	0.275,-0.360	0.900,-1.980	0.750,-2.170	0.386,-2.330
1,0.000	1.025,0.055	0.275,0.075	0.900,0.330	0.750,0.305	0.386,0.315
1,0.000	1.025,-0.050	0.275,9.325	0.900,51.550	0.750,61.380	0.386,62.510
1,0.000	1.025,-0.030	0.275,-0.050	0.900,-1.530	0.750,-2.930	0.386,-2.850
1,0.000	1.025,0.020	0.275,0.325	0.900,3.415	0.750,2.700	0.386,2.800
1,0.000	1.025,-0.100	0.275,-0.115	0.900,0.100	0.750,0.385	0.386,0.495
1,0.000	1.025,0.125	0.275,0.180	0.900,0.300	0.750,0.390	0.386,0.320
1,0.000	1.025,-0.030	0.275,0.010	0.900,0.005	0.750,-0.020	0.386,-0.010
1,0.000	1.025,0.030	0.275,0.110	0.900,1.640	0.750,3.150	0.386,3.300
1,0.000	1.025,-0.180	0.275,-0.110	0.900,-0.100	0.750,-0.440	0.386,-0.325
1,0.000	1.025,0.220	0.275,0.060	0.900,-0.580	0.750,-1.090	0.386,-1.170
1,0.000	1.025,-0.120	0.275,-0.135	0.900,-0.155	0.750,-0.050	0.386,0.020
1,0.000	1.025,0.110	0.275,0.110	0.900,0.165	0.750,0.270	0.386,0.280

1,0.000	1.025,0.005	0.275,0.020	0.900,0.040	0.750,0.030	0.386,0.025
1,0.000	1.025,-0.170	0.275,-0.200	0.900,0.140	0.750,0.770	0.386,0.980
1,0.000	1.025,-0.270	0.275,-0.310	0.900,-0.005	0.750,0.090	0.386,0.230
1,0.000	1.025,-0.085	0.275,-0.200	0.900,-0.345	0.750,-0.515	0.386,-0.605

Appendix K: Behavior Gaze Shift GWTs

Each GWT consists of six keyframes covering 18 degrees of freedom. The degrees of freedom are X, Y, Z, Roll, Pitch, and Yaw for each of the three sensors, head, shoulders, and lower back. The first term in each element of the GWT is the time scaling parameter, which will scale the time at which the keyframe will occur. The second term in each element is the curve displacement parameter, which will modify the actual values of the curve. These GWTs are the combinations of gaze behaviors described in Chapter 5 that are used to produce emotionally expressive gaze shifts by applying them to an emotionally neutral gaze shift.

head bowed, torso bowed, velocity fast

1,0.000	0.281,0.065	0.500,-0.155	0.323,-1.055	0.538,-1.645	1,-1.990
1,0.000	0.281,-0.215	0.500,1.450	0.323,8.305	0.538,9.845	1,10.140
1,0.000	0.281,0.000	0.500,0.330	0.323,2.650	0.538,3.470	1,3.620
1,0.000	0.281,-0.430	0.500,0.455	0.323,-2.160	0.538,-3.415	1,-5.185
1,0.000	0.281,-0.115	0.500,-3.655	0.323,-25.910	0.538,-29.145	1,-29.220
1,0.000	0.281,0.060	0.500,0.090	0.323,-7.520	0.538,-7.785	1,-6.970
1,0.000	0.281,0.110	0.500,0.320	0.323,0.875	0.538,0.810	1,0.670
1,0.000	0.281,-0.215	0.500,0.480	0.323,3.090	0.538,4.255	1,4.445
1,0.000	0.281,0.020	0.500,-0.390	0.323,-1.050	0.538,-0.925	1,-0.900
1,0.000	0.281,0.205	0.500,1.270	0.323,3.715	0.538,4.380	1,4.640
1,0.000	0.281,0.240	0.500,-6.420	0.323,-26.860	0.538,-31.640	1,-32.300
1,0.000	0.281,0.185	0.500,0.095	0.323,1.075	0.538,1.905	1,3.080
1,0.000	0.281,0.100	0.500,0.200	0.323,0.260	0.538,0.295	1,0.350
1,0.000	0.281,-0.170	0.500,-0.120	0.323,-0.480	0.538,-0.330	1,-0.300
1,0.000	0.281,-0.075	0.500,-0.010	0.323,-0.295	0.538,-0.375	1,-0.400
1,0.000	0.281,0.410	0.500,0.240	0.323,-0.340	0.538,0.130	1,0.645
1,0.000	0.281,-0.065	0.500,0.560	0.323,-3.690	0.538,-7.335	1,-8.150
1,0.000	0.281,-0.010	0.500,0.405	0.323,1.650	0.538,0.175	1,0.390

head bowed, torso bowed, velocity neutral

1,0.000	1,0.085	1,-0.120	1,-1.030	1,-1.755	1,-2.100
1,0.000	1,-0.125	1,1.625	1,8.765	1,10.325	1,10.550
1,0.000	1,0.040	1,0.310	1,2.575	1,3.430	1,3.590
1,0.000	1,-0.300	1,0.550	1,-5.015	1,-7.955	1,-8.890
1,0.000	1,-0.100	1,-3.620	1,-24.810	1,-27.485	1,-27.600
1,0.000	1,-0.045	1,-0.220	1,-9.105	1,-8.980	1,-8.010
1,0.000	1,0.095	1,0.270	1,0.735	1,0.615	1,0.415
1,0.000	1,-0.155	1,0.625	1,3.420	1,4.575	1,4.740
1,0.000	1,0.010	1,-0.355	1,-1.045	1,-0.895	1,-0.870
1,0.000	1,0.055	1,1.140	1,3.255	1,3.490	1,3.420
1,0.000	1,0.240	1,-6.395	1,-27.200	1,-31.900	1,-32.500
1,0.000	1,0.190	1,0.000	1,1.040	1,1.870	1,3.155
1,0.000	1,0.095	1,0.185	1,0.215	1,0.265	1,0.270
1,0.000	1,-0.125	1,-0.085	1,-0.330	1,-0.060	1,0.010
1,0.000	1,-0.050	1,0.035	1,-0.210	1,-0.315	1,-0.340
1,0.000	1,0.240	1,-0.005	1,-0.620	1,-0.120	1,-0.050
1,0.000	1,-0.120	1,0.460	1,-3.610	1,-7.145	1,-7.970
1,0.000	1,-0.185	1,0.220	1,1.310	1,0.080	1,0.355

head bowed, torso bowed, velocity slow

1,0.000	0.844,0.065	4.375,-0.090	2.194,-0.815	1.462,-1.495	2.444,-1.840
1,0.000	0.844,-0.215	4.375,1.415	2.194,8.315	1.462,9.955	2.444,10.260
1,0.000	0.844,0.000	4.375,0.295	2.194,2.560	1.462,3.420	2.444,3.590
1,0.000	0.844,-0.260	4.375,1.280	2.194,-3.635	1.462,-6.525	2.444,-7.520
1,0.000	0.844,-0.095	4.375,-3.400	2.194,-23.290	1.462,-26.615	2.444,-27.010
1,0.000	0.844,0.075	4.375,-0.100	2.194,-8.930	1.462,-8.890	2.444,-7.990
1,0.000	0.844,0.125	4.375,0.330	2.194,0.925	1.462,0.845	2.444,0.675
1,0.000	0.844,-0.205	4.375,0.485	2.194,3.110	1.462,4.315	2.444,4.530
1,0.000	0.844,0.020	4.375,-0.380	2.194,-1.010	1.462,-0.895	2.444,-0.860
1,0.000	0.844,0.165	4.375,1.330	2.194,4.380	1.462,4.880	2.444,4.850
1,0.000	0.844,0.335	4.375,-6.215	2.194,-26.700	1.462,-31.560	2.444,-32.250
1,0.000	0.844,0.095	4.375,0.000	2.194,0.780	1.462,1.520	2.444,2.695
1,0.000	0.844,0.115	4.375,0.195	2.194,0.315	1.462,0.340	2.444,0.350
1,0.000	0.844,-0.170	4.375,-0.150	2.194,-0.550	1.462,-0.340	2.444,-0.210
1,0.000	0.844,-0.065	4.375,0.000	2.194,-0.280	1.462,-0.355	2.444,-0.370
1,0.000	0.844,0.300	4.375,0.150	2.194,0.225	1.462,0.730	2.444,0.890
1,0.000	0.844,-0.125	4.375,0.470	2.194,-3.050	1.462,-6.665	2.444,-7.520
1,0.000	0.844,-0.155	4.375,0.190	2.194,1.500	1.462,0.100	2.444,0.305

head bowed, torso neutral, velocity fast

1,0.000	0.281,0.105	0.500,-0.120	0.323,-1.115	0.538,-1.535	1,-1.795
1,0.000	0.281,-0.075	0.500,0.125	0.323,1.925	0.538,2.285	1,2.450
1,0.000	0.281,-0.030	0.500,0.265	0.323,1.560	0.538,1.870	1,1.940
1,0.000	0.281,-0.430	0.500,0.875	0.323,-0.780	0.538,0.295	1,-1.085
1,0.000	0.281,-0.220	0.500,-3.905	0.323,-26.090	0.538,-31.975	1,-32.170
1,0.000	0.281,-0.120	0.500,-0.720	0.323,-9.300	0.538,-10.675	1,-10.150
1,0.000	0.281,0.130	0.500,0.315	0.323,0.765	0.538,0.780	1,0.680
1,0.000	0.281,-0.120	0.500,-0.375	0.323,-1.490	0.538,-1.580	1,-1.535
1,0.000	0.281,-0.030	0.500,-0.060	0.323,0.120	0.538,0.170	1,0.170
1,0.000	0.281,0.215	0.500,1.440	0.323,5.375	0.538,5.990	1,6.310
1,0.000	0.281,-0.210	0.500,-1.975	0.323,-3.900	0.538,-4.610	1,-4.910
1,0.000	0.281,0.035	0.500,-0.025	0.323,-0.045	0.538,0.185	1,1.075
1,0.000	0.281,0.110	0.500,0.180	0.323,0.160	0.538,0.115	1,0.155
1,0.000	0.281,-0.145	0.500,-0.160	0.323,-0.450	0.538,-0.570	1,-0.620
1,0.000	0.281,-0.060	0.500,0.000	0.323,0.535	0.538,0.685	1,0.710
1,0.000	0.281,0.280	0.500,0.190	0.323,0.060	0.538,-0.300	1,0.085
1,0.000	0.281,-0.070	0.500,0.510	0.323,4.550	0.538,4.560	1,4.490
1,0.000	0.281,-0.005	0.500,0.235	0.323,2.160	0.538,2.035	1,2.275

head bowed, torso neutral, velocity neutral

1,0.000	1,0.125	1,-0.085	1,-1.090	1,-1.645	1,-1.905
1,0.000	1,0.015	1,0.300	1,2.385	1,2.765	1,2.860
1,0.000	1,0.010	1,0.245	1,1.485	1,1.830	1,1.910
1,0.000	1,-0.300	1,0.970	1,-3.635	1,-4.245	1,-4.790
1,0.000	1,-0.205	1,-3.870	1,-24.990	1,-30.315	1,-30.550
1,0.000	1,-0.225	1,-1.030	1,-10.885	1,-11.870	1,-11.190
1,0.000	1,0.115	1,0.265	1,0.625	1,0.585	1,0.425
1,0.000	1,-0.060	1,-0.230	1,-1.160	1,-1.260	1,-1.240
1,0.000	1,-0.040	1,-0.025	1,0.125	1,0.200	1,0.200
1,0.000	1,0.065	1,1.310	1,4.915	1,5.100	1,5.090
1,0.000	1,-0.210	1,-1.950	1,-4.240	1,-4.870	1,-5.110
1,0.000	1,0.040	1,-0.120	1,-0.080	1,0.150	1,1.150
1,0.000	1,0.105	1,0.165	1,0.115	1,0.085	1,0.075
1,0.000	1,-0.100	1,-0.125	1,-0.300	1,-0.300	1,-0.310
1,0.000	1,-0.035	1,0.045	1,0.620	1,0.745	1,0.770
1,0.000	1,0.110	1,-0.055	1,-0.220	1,-0.550	1,-0.610
1,0.000	1,-0.125	1,0.410	1,4.630	1,4.750	1,4.670
1,0.000	1,-0.180	1,0.050	1,1.820	1,1.940	1,2.240

head bowed, torso neutral, velocity slow

1,0.000	0.844,0.105	4.375,-0.055	2.194,-0.875	1.462,-1.385	2.444,-1.645
1,0.000	0.844,-0.075	4.375,0.090	2.194,1.935	1.462,2.395	2.444,2.570
1,0.000	0.844,-0.030	4.375,0.230	2.194,1.470	1.462,1.820	2.444,1.910
1,0.000	0.844,-0.260	4.375,1.700	2.194,-2.255	1.462,-2.815	2.444,-3.420
1,0.000	0.844,-0.200	4.375,-3.650	2.194,-23.470	1.462,-29.445	2.444,-29.960
1,0.000	0.844,-0.105	4.375,-0.910	2.194,-10.710	1.462,-11.780	2.444,-11.170
1,0.000	0.844,0.145	4.375,0.325	2.194,0.815	1.462,0.815	2.444,0.685

1,0.000	0.844,-0.110	4.375,-0.370	2.194,-1.470	1.462,-1.520	2.444,-1.450
1,0.000	0.844,-0.030	4.375,-0.050	2.194,0.160	1.462,0.200	2.444,0.210
1,0.000	0.844,0.175	4.375,1.500	2.194,6.040	1.462,6.490	2.444,6.520
1,0.000	0.844,-0.115	4.375,-1.770	2.194,-3.740	1.462,-4.530	2.444,-4.860
1,0.000	0.844,-0.055	4.375,-0.120	2.194,-0.340	1.462,-0.200	2.444,0.690
1,0.000	0.844,0.125	4.375,0.175	2.194,0.215	1.462,0.160	2.444,0.155
1,0.000	0.844,-0.145	4.375,-0.190	2.194,-0.520	1.462,-0.580	2.444,-0.530
1,0.000	0.844,-0.050	4.375,0.010	2.194,0.550	1.462,0.705	2.444,0.740
1,0.000	0.844,0.170	4.375,0.100	2.194,0.625	1.462,0.300	2.444,0.330
1,0.000	0.844,-0.130	4.375,0.420	2.194,5.190	1.462,5.230	2.444,5.120
1,0.000	0.844,-0.150	4.375,0.020	2.194,2.010	1.462,1.960	2.444,2.190

head high, torso neutral, velocity fast

1,0.000	0.281,0.040	0.500,0.165	0.323,0.835	0.538,0.990	1,0.970
1,0.000	0.281,-0.180	0.500,-0.585	0.323,-1.165	0.538,-1.225	1,-1.210
1,0.000	0.281,-0.020	0.500,0.065	0.323,0.715	0.538,0.925	1,0.970
1,0.000	0.281,-0.570	0.500,1.335	0.323,10.030	0.538,12.605	1,12.015
1,0.000	0.281,0.090	0.500,3.525	0.323,17.205	0.538,19.505	1,19.940
1,0.000	0.281,-0.025	0.500,1.070	0.323,8.140	0.538,11.130	1,11.560
1,0.000	0.281,0.065	0.500,0.130	0.323,0.510	0.538,0.645	1,0.695
1,0.000	0.281,-0.170	0.500,-0.245	0.323,-0.045	0.538,0.060	1,0.045
1,0.000	0.281,0.010	0.500,0.000	0.323,-0.165	0.538,-0.195	1,-0.210
1,0.000	0.281,0.110	0.500,0.270	0.323,3.795	0.538,4.800	1,5.090
1,0.000	0.281,-0.010	0.500,0.065	0.323,-1.160	0.538,-1.350	1,-1.310
1,0.000	0.281,0.105	0.500,0.165	0.323,0.855	0.538,0.645	1,0.605
1,0.000	0.281,0.055	0.500,0.145	0.323,0.480	0.538,0.525	1,0.570
1,0.000	0.281,-0.140	0.500,-0.170	0.323,-0.260	0.538,-0.325	1,-0.400
1,0.000	0.281,-0.050	0.500,-0.060	0.323,-0.155	0.538,-0.160	1,-0.170
1,0.000	0.281,0.320	0.500,0.490	0.323,2.980	0.538,3.470	1,3.925
1,0.000	0.281,0.230	0.500,0.630	0.323,1.310	0.538,1.170	1,1.160
1,0.000	0.281,0.195	0.500,0.425	0.323,0.770	0.538,0.525	1,0.575

head high, torso neutral, velocity neutral

1,0.000	1,0.060	1,0.200	1,0.860	1,0.880	1,0.860
1,0.000	1,-0.090	1,-0.410	1,-0.705	1,-0.745	1,-0.800
1,0.000	1,0.020	1,0.045	1,0.640	1,0.885	1,0.940
1,0.000	1,-0.440	1,1.430	1,7.175	1,8.065	1,8.310
1,0.000	1,0.105	1,3.560	1,18.305	1,21.165	1,21.560
1,0.000	1,-0.130	1,0.760	1,6.555	1,9.935	1,10.520
1,0.000	1,0.050	1,0.080	1,0.370	1,0.450	1,0.440
1,0.000	1,-0.110	1,-0.100	1,0.285	1,0.380	1,0.340
1,0.000	1,0.000	1,0.035	1,-0.160	1,-0.165	1,-0.180
1,0.000	1,-0.040	1,0.140	1,3.335	1,3.910	1,3.870
1,0.000	1,-0.010	1,0.090	1,-1.500	1,-1.610	1,-1.510
1,0.000	1,0.110	1,0.070	1,0.820	1,0.610	1,0.680
1,0.000	1,0.050	1,0.130	1,0.435	1,0.495	1,0.490
1,0.000	1,-0.095	1,-0.135	1,-0.110	1,-0.055	1,-0.090
1,0.000	1,-0.025	1,-0.015	1,-0.070	1,-0.100	1,-0.110
1,0.000	1,0.150	1,0.245	1,2.700	1,3.220	1,3.230
1,0.000	1,0.175	1,0.530	1,1.390	1,1.360	1,1.340
1,0.000	1,0.020	1,0.240	1,0.430	1,0.430	1,0.540

head high, torso neutral, velocity slow

1,0.000	0.844,0.040	4.375,0.230	2.194,1.075	1.462,1.140	2.444,1.120
1,0.000	0.844,-0.180	4.375,-0.620	2.194,-1.155	1.462,-1.115	2.444,-1.090
1,0.000	0.844,-0.020	4.375,0.030	2.194,0.625	1.462,0.875	2.444,0.940
1,0.000	0.844,-0.400	4.375,2.160	2.194,8.555	1.462,9.495	2.444,9.680
1,0.000	0.844,0.110	4.375,3.780	2.194,19.825	1.462,22.035	2.444,22.150
1,0.000	0.844,-0.010	4.375,0.880	2.194,6.730	1.462,10.025	2.444,10.540
1,0.000	0.844,0.080	4.375,0.140	2.194,0.560	1.462,0.680	2.444,0.700
1,0.000	0.844,-0.160	4.375,-0.240	2.194,-0.025	1.462,0.120	2.444,0.130
1,0.000	0.844,0.010	4.375,0.010	2.194,-0.125	1.462,-0.165	2.444,-0.170
1,0.000	0.844,0.070	4.375,0.330	2.194,4.460	1.462,5.300	2.444,5.300
1,0.000	0.844,0.085	4.375,0.270	2.194,-1	1.462,-1.270	2.444,-1.260
1,0.000	0.844,0.015	4.375,0.070	2.194,0.560	1.462,0.260	2.444,0.220
1,0.000	0.844,0.070	4.375,0.140	2.194,0.535	1.462,0.570	2.444,0.570
1,0.000	0.844,-0.140	4.375,-0.200	2.194,-0.330	1.462,-0.335	2.444,-0.310
1,0.000	0.844,-0.040	4.375,-0.050	2.194,-0.140	1.462,-0.140	2.444,-0.140

1,0.000	0.844,0.210	4.375,0.400	2.194,3.545	1.462,4.070	2.444,4.170
1,0.000	0.844,0.170	4.375,0.540	2.194,1.950	1.462,1.840	2.444,1.790
1,0.000	0.844,0.050	4.375,0.210	2.194,0.620	1.462,0.450	2.444,0.490

head neutral, torso bowed, velocity fast

1,0.000	0.281,-0.030	0.500,-0.070	0.323,0.060	0.538,0.010	1,-0.085
1,0.000	0.281,-0.270	0.500,1.090	0.323,6.005	0.538,7.140	1,7.280
1,0.000	0.281,0.020	0.500,0.090	0.323,1.170	0.538,1.640	1,1.710
1,0.000	0.281,-0.120	0.500,-0.515	0.323,1.430	0.538,0.810	1,-0.395
1,0.000	0.281,0.140	0.500,0.255	0.323,-1.030	0.538,1.100	1,1.330
1,0.000	0.281,0.205	0.500,1.210	0.323,3.250	0.538,4.045	1,4.220
1,0.000	0.281,-0.005	0.500,0.055	0.323,0.250	0.538,0.235	1,0.245
1,0.000	0.281,-0.185	0.500,0.710	0.323,4.330	0.538,5.575	1,5.685
1,0.000	0.281,0.050	0.500,-0.330	0.323,-1.190	0.538,-1.115	1,-1.100
1,0.000	0.281,0.110	0.500,0.010	0.323,-1.125	0.538,-0.690	1,-0.450
1,0.000	0.281,0.470	0.500,-4.350	0.323,-22.760	0.538,-26.840	1,-27.190
1,0.000	0.281,0.165	0.500,0.105	0.323,1.145	0.538,1.665	1,1.930
1,0.000	0.281,-0.005	0.500,0.045	0.323,0.115	0.538,0.205	1,0.275
1,0.000	0.281,-0.090	0.500,-0.030	0.323,-0.170	0.538,0.020	1,0.010
1,0.000	0.281,-0.045	0.500,-0.040	0.323,-0.875	0.538,-1.110	1,-1.170
1,0.000	0.281,0.320	0.500,0.260	0.323,-0.190	0.538,0.700	1,1.255
1,0.000	0.281,0.040	0.500,0.150	0.323,-8.320	0.538,-12.085	1,-12.820
1,0.000	0.281,0.080	0.500,0.295	0.323,-0.370	0.538,-1.855	1,-1.850

head neutral, torso bowed, velocity neutral

1,0.000	1,-0.010	1,-0.035	1,0.085	1,-0.100	1,-0.195
1,0.000	1,-0.180	1,1.265	1,6.465	1,7.620	1,7.690
1,0.000	1,0.060	1,0.070	1,1.095	1,1.600	1,1.680
1,0.000	1,0.010	1,-0.420	1,-1.425	1,-3.730	1,-4.100
1,0.000	1,0.155	1,0.290	1,0.070	1,2.760	1,2.950
1,0.000	1,0.100	1,0.900	1,1.665	1,2.850	1,3.180
1,0.000	1,-0.020	1,0.005	1,0.110	1,0.040	1,-0.010
1,0.000	1,-0.125	1,0.855	1,4.660	1,5.895	1,5.980
1,0.000	1,0.040	1,-0.295	1,-1.185	1,-1.085	1,-1.070
1,0.000	1,-0.040	1,-0.120	1,-1.585	1,-1.580	1,-1.670
1,0.000	1,0.470	1,-4.325	1,-23.100	1,-27.100	1,-27.390
1,0.000	1,0.170	1,0.010	1,1.110	1,1.630	1,2.005
1,0.000	1,-0.010	1,0.030	1,0.070	1,0.175	1,0.195
1,0.000	1,-0.045	1,0.005	1,-0.020	1,0.290	1,0.320
1,0.000	1,-0.020	1,0.005	1,-0.790	1,-1.050	1,-1.110
1,0.000	1,0.150	1,0.015	1,-0.470	1,0.450	1,0.560
1,0.000	1,-0.015	1,0.050	1,-8.240	1,-11.895	1,-12.640
1,0.000	1,-0.095	1,0.110	1,-0.710	1,-1.950	1,-1.885

head neutral, torso bowed, velocity slow

1,0.000	0.844,-0.030	4.375,-0.005	2.194,0.300	1.462,0.160	2.444,0.065
1,0.000	0.844,-0.270	4.375,1.055	2.194,6.015	1.462,7.250	2.444,7.400
1,0.000	0.844,0.020	4.375,0.055	2.194,1.080	1.462,1.590	2.444,1.680
1,0.000	0.844,0.050	4.375,0.310	2.194,-0.045	1.462,-2.300	2.444,-2.730
1,0.000	0.844,0.160	4.375,0.510	2.194,1.590	1.462,3.630	2.444,3.540
1,0.000	0.844,0.220	4.375,1.020	2.194,1.840	1.462,2.940	2.444,3.200
1,0.000	0.844,0.010	4.375,0.065	2.194,0.300	1.462,0.270	2.444,0.250
1,0.000	0.844,-0.175	4.375,0.715	2.194,4.350	1.462,5.635	2.444,5.770
1,0.000	0.844,0.050	4.375,-0.320	2.194,-1.150	1.462,-1.085	2.444,-1.060
1,0.000	0.844,0.070	4.375,0.070	2.194,-0.460	1.462,-0.190	2.444,-0.240
1,0.000	0.844,0.565	4.375,-4.145	2.194,-22.600	1.462,-26.760	2.444,-27.140
1,0.000	0.844,0.075	4.375,0.010	2.194,0.850	1.462,1.280	2.444,1.545
1,0.000	0.844,0.010	4.375,0.040	2.194,0.170	1.462,0.250	2.444,0.275
1,0.000	0.844,-0.090	4.375,-0.060	2.194,-0.240	1.462,0.010	2.444,0.100
1,0.000	0.844,-0.035	4.375,-0.030	2.194,-0.860	1.462,-1.090	2.444,-1.140
1,0.000	0.844,0.210	4.375,0.170	2.194,0.375	1.462,1.300	2.444,1.500
1,0.000	0.844,-0.020	4.375,0.060	2.194,-7.680	1.462,-11.415	2.444,-12.190
1,0.000	0.844,-0.065	4.375,0.080	2.194,-0.520	1.462,-1.930	2.444,-1.935

head neutral, torso neutral, velocity neutral

1,0.000	1,0.030	1,0.000	1,0.025	1,0.010	1,0.000
1,0.000	1,-0.040	1,-0.060	1,0.085	1,0.060	1,0.000
1,0.000	1,0.030	1,0.005	1,0.005	1,0.000	1,0.000

1,0.000	1,0.010	1,0.000	1,-0.045	1,-0.020	1,0.000
1,0.000	1,0.050	1,0.040	1,-0.110	1,-0.070	1,0.000
1,0.000	1,-0.080	1,0.090	1,-0.115	1,-0.040	1,0.000
1,0.000	1,0.000	1,0.000	1,0.000	1,0.010	1,0.000
1,0.000	1,-0.030	1,0.000	1,0.080	1,0.060	1,0.000
1,0.000	1,-0.010	1,0.035	1,-0.015	1,0.010	1,0.000
1,0.000	1,-0.030	1,0.050	1,0.075	1,0.030	1,0.000
1,0.000	1,0.020	1,0.120	1,-0.140	1,-0.070	1,0.000
1,0.000	1,0.020	1,-0.110	1,-0.010	1,-0.090	1,0.000
1,0.000	1,0.000	1,0.010	1,-0.030	1,-0.005	1,0.000
1,0.000	1,-0.020	1,-0.035	1,0.010	1,0.050	1,0.000
1,0.000	1,-0.005	1,0.015	1,0.040	1,0.010	1,0.000
1,0.000	1,0.020	1,-0.035	1,-0.070	1,0.020	1,0.000
1,0.000	1,-0.020	1,0.000	1,0.000	1,0.000	1,0.000
1,0.000	1,-0.090	1,-0.060	1,-0.200	1,-0.090	1,0.000

head neutral, torso neutral, velocity fast

1,0.000	0.281,0.010	0.500,-0.035	0.323,0.000	0.538,0.120	1,0.110
1,0.000	0.281,-0.130	0.500,-0.235	0.323,-0.375	0.538,-0.420	1,-0.410
1,0.000	0.281,-0.010	0.500,0.025	0.323,0.080	0.538,0.040	1,0.030
1,0.000	0.281,-0.120	0.500,-0.095	0.323,2.810	0.538,4.520	1,3.705
1,0.000	0.281,0.035	0.500,0.005	0.323,-1.210	0.538,-1.730	1,-1.620
1,0.000	0.281,0.025	0.500,0.400	0.323,1.470	0.538,1.155	1,1.040
1,0.000	0.281,0.015	0.500,0.050	0.323,0.140	0.538,0.205	1,0.255
1,0.000	0.281,-0.090	0.500,-0.145	0.323,-0.250	0.538,-0.260	1,-0.295
1,0.000	0.281,0.000	0.500,0.000	0.323,-0.020	0.538,-0.020	1,-0.030
1,0.000	0.281,0.120	0.500,0.180	0.323,0.535	0.538,0.920	1,1.220
1,0.000	0.281,0.020	0.500,0.095	0.323,0.200	0.538,0.190	1,0.200
1,0.000	0.281,0.015	0.500,-0.015	0.323,0.025	0.538,-0.055	1,-0.075
1,0.000	0.281,0.005	0.500,0.025	0.323,0.015	0.538,0.025	1,0.080
1,0.000	0.281,-0.065	0.500,-0.070	0.323,-0.140	0.538,-0.220	1,-0.310
1,0.000	0.281,-0.030	0.500,-0.030	0.323,-0.045	0.538,-0.050	1,-0.060
1,0.000	0.281,0.190	0.500,0.210	0.323,0.210	0.538,0.270	1,0.695
1,0.000	0.281,0.035	0.500,0.100	0.323,-0.080	0.538,-0.190	1,-0.180
1,0.000	0.281,0.085	0.500,0.125	0.323,0.140	0.538,0.005	1,0.035

head neutral, torso neutral, velocity neutral

1,0.000	1,0.060	1,0.000	1,0.050	1,0.020	1,0.000
1,0.000	1,-0.080	1,-0.120	1,0.170	1,0.120	1,0.000
1,0.000	1,0.060	1,0.010	1,0.010	1,0.000	1,0.000
1,0.000	1,0.020	1,0.000	1,-0.090	1,-0.040	1,0.000
1,0.000	1,0.100	1,0.080	1,-0.220	1,-0.140	1,0.000
1,0.000	1,-0.160	1,0.180	1,-0.230	1,-0.080	1,0.000
1,0.000	1,0.000	1,0.000	1,0.000	1,0.020	1,0.000
1,0.000	1,-0.060	1,0.000	1,0.160	1,0.120	1,0.000
1,0.000	1,-0.020	1,0.070	1,-0.030	1,0.020	1,0.000
1,0.000	1,-0.060	1,0.100	1,0.150	1,0.060	1,0.000
1,0.000	1,0.040	1,0.240	1,-0.280	1,-0.140	1,0.000
1,0.000	1,0.040	1,-0.220	1,-0.020	1,-0.180	1,0.000
1,0.000	1,0.000	1,0.020	1,-0.060	1,-0.010	1,0.000
1,0.000	1,-0.040	1,-0.070	1,0.020	1,0.100	1,0.000
1,0.000	1,-0.010	1,0.030	1,0.080	1,0.020	1,0.000
1,0.000	1,0.040	1,-0.070	1,-0.140	1,0.040	1,0.000
1,0.000	1,-0.040	1,0.000	1,0.000	1,0.000	1,0.000
1,0.000	1,-0.180	1,-0.120	1,-0.400	1,-0.180	1,0.000

head neutral, torso neutral, velocity slow

1,0.000	0.844,0.010	4.375,0.030	2.194,0.240	1.462,0.270	2.444,0.260
1,0.000	0.844,-0.130	4.375,-0.270	2.194,-0.365	1.462,-0.310	2.444,-0.290
1,0.000	0.844,-0.010	4.375,-0.010	2.194,-0.010	1.462,-0.010	2.444,0.000
1,0.000	0.844,0.050	4.375,0.730	2.194,1.335	1.462,1.410	2.444,1.370
1,0.000	0.844,0.055	4.375,0.260	2.194,1.410	1.462,0.800	2.444,0.590
1,0.000	0.844,0.040	4.375,0.210	2.194,0.060	1.462,0.050	2.444,0.020
1,0.000	0.844,0.030	4.375,0.060	2.194,0.190	1.462,0.240	2.444,0.260
1,0.000	0.844,-0.080	4.375,-0.140	2.194,-0.230	1.462,-0.200	2.444,-0.210
1,0.000	0.844,0.000	4.375,0.010	2.194,0.020	1.462,0.010	2.444,0.010
1,0.000	0.844,0.080	4.375,0.240	2.194,1.200	1.462,1.420	2.444,1.430
1,0.000	0.844,0.115	4.375,0.300	2.194,0.360	1.462,0.270	2.444,0.250

1,0.000	0.844,-0.075	4.375,-0.110	2.194,-0.270	1.462,-0.440	2.444,-0.460
1,0.000	0.844,0.020	4.375,0.020	2.194,0.070	1.462,0.070	2.444,0.080
1,0.000	0.844,-0.065	4.375,-0.100	2.194,-0.210	1.462,-0.230	2.444,-0.220
1,0.000	0.844,-0.020	4.375,-0.020	2.194,-0.030	1.462,-0.030	2.444,-0.030
1,0.000	0.844,0.080	4.375,0.120	2.194,0.775	1.462,0.870	2.444,0.940
1,0.000	0.844,-0.025	4.375,0.010	2.194,0.560	1.462,0.480	2.444,0.450
1,0.000	0.844,-0.060	4.375,-0.090	2.194,-0.010	1.462,-0.070	2.444,-0.050