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LESSONS FROM THE ARTS: WHAT THE PERFORMING ARTS LITERATURE CAN TEACH US ABOUT CREATING EXPRESSIVE CHARACTER MOVEMENT

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The performing arts literature offers arguably the most comprehensive analysis of expressive character movement available. While it is not always straightforward to apply material written for human performers to virtual characters, this material provides excellent guidance on the movement repertoire we need to imbue synthetic characters with in order to give them rich personalities and strong emotional expression. This chapter reviews material from actor training, animation and movement theory in order to provide a broad grounding in the movement principles distilled in the arts. It also discusses some of the challenges in using this material and shows examples of how it can be successfully applied for procedural animation. The chapter aims to provide a clear understanding of the kinds of movement characters in virtual worlds will likely require in order to convey rich personalities and emotional nuance.

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MICHAEL NEFF ON HIS METHODS

This work is motivated by the goal of creating computer tools that allow the easy generation of expressive characters for virtual worlds. In support of this goal, the chapter provides a broad overview of movement insights gained from the arts. This knowledge was gained from three different ways of understanding expressive movement: secondary research in the arts literature, embodied knowledge from movement training and applied work representing movement in computer animation tools. It is argued that this understanding of movement provides a basis for understanding the types of movement necessary for virtual characters.

The literature based research has been approached by completing a broad survey of writings on expressive movement, including research on actor training, mime, clown, animation and movement

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No field has studied character movement more intently than the performing arts as expressive motion is critical for creating the rich characters that have been produced on stage for centuries, and more recently, in film and animation. One of the great challenges in building character systems for virtual worlds is generating such movement that can express a character's unique personality and change appropriately with his/her changing mood. As this challenge is also at the heart of the work of actors and animators, we can learn from the substantial literature outlining the principles they have uncovered.

This chapter has three goals. First and foremost, it will summarize the key movement properties discussed in the arts literature, with a focus on material most useful for virtual characters. Emphasis will be placed on understanding which movement aspects support the expression of personality and emotion, with a brief discussion of action selection. These movement qualities provide the palette that we use to design virtual characters and it is thus crucial to have a clear understanding of them. The second goal of the chapter is to show how these ideas have been incorporated into computational models for animation. This will be done through "implementations" sections, placed alongside a description of the qualities. I will discuss my own work in this area, as I know it best, but also try to link to the significant amount of important work done by other researchers. This will necessarily be incomplete and I apologize if I fail to mention worthwhile work for reasons of space. Finally, the chapter will conclude with a discussion of the challenges inherent in applying this material computationally and discuss potential future uses of the material.

A comprehensive summary of the key properties of expressive movement provides a map that outlines the qualities any character animation system should seek to support. This chapter argues that this material offers significant value no matter the motion representation used, as it can inform the design of procedural algorithms for motion control, provide guidance for building a motion capture library working with a team of actors, or be used as a measuring stick to gauge the completeness of learning based approaches.

theory. Through a synthesis process, movement properties that are repeated across the literature are identified and categorized. These "common properties" provide a good basis for understanding movement. This survey focuses on "functional" or "objective" descriptions of movement, i.e. what the body is actually doing, and supplements this by possible meanings implied by those movements. These functional descriptions lend themselves more readily to computational representation.

The literature based research is tested in two ways: against embodied experience and for its ability to support computational models. Practical movement work provides the quickest and most effective way to explore movement ideas. We can try them out in our body and observe them in others and through this gain a deeper understanding of how they function and what they mean. I've experimented with most of the properties discussed in the chapter through my own movement practice, particularly in my training to become a Certified Laban Movement Analyst. For virtual worlds, movement must ultimately be mapped to a computational representation. Performing this mapping process both reveals whether the property is clearly understood and indicates which movement properties lend themselves most easily to computational use and where future research challenges lie. I've spent several years developing computational models of movement based on these insights.

1. SIDEBAR: A BRIEF INTRODUCTION TO COMPUTER ANIMATION

It is helpful to introduce some basic animation concepts and terminology in order to be able to discuss how ideas from the arts have been applied computationally. Characters are generally represented computationally by a skeleton, a set of fixed length bones connected by joints. Movement is specified by changing the angles of these joints over time. Joints may rotate in up to three dimensions (x, y, z) and each of these rotations is referred to as a *Degree of Freedom* (DOF). The visual appearance of the character is normally defined by a 3D mesh which is bound to the skeleton and deformed by its movement.

Most researchers that have sought to leverage off material from the arts have done so by building *procedural models*, i.e. they have written software that encodes particular movement ideas. A common representation is to divide movement into a series of *poses* specified at particular points in time, known as *keyframes* in traditional animation. These poses may be specified by providing the value of all the joint angles in the skeleton or by providing the position of key body parts, such as the hands.

Interpolation is the process of moving from one pose to the next, something known as *inbetweening* in traditional animation. There is a wide range of velocity profiles that can be used in making these transitions and this is referred to as the *motion envelope*.

Forward Kinematics (FK) is the process of solving for the character pose based on a specified set of joint angles. *Inverse Kinematics* (IK) is the process of solving for a set of joint angles that will satisfy a world space constraint, such as the position of the character's hand. You can think of FK as controlling the character through joint angles and IK as controlling the character by specifying positions for body parts.

2. KEY SOURCES

This work draws on three main fields that have studied expressive movement in the context of creating convincing characters: traditional animation, actor training and movement theory. The paper will synthesize findings across these fields rather than adopting a single framework.

For traditional animation, we rely on the work of Thomas and Johnston (1981) and Lasseter (1987) that describes the principles of traditional animation developed at the Disney studio in the 1930's. These are: Squash and Stretch (deforming a character to show its mass and rigidity/fluid nature), Timing (spacing actions to reveal a sense of weight and personality), Anticipation (preparing the audience for what is about to happen), Staging (arranging action so that it is easily read by an audience), Follow Through and Overlapping Action (different parts of the body should start and stop at different times; one action should flow into, and overlap with, the next), Straight Ahead Action and Pose-To-Pose Action (drawing either every frame in a sequence or first drawing key moments and then filling in the in-betweens), Slow In and Out (adjusting the spacing between key poses), Arcs (using curved paths through space to give more natural movement), Exaggeration (emphasizing the key points to be communicated), Secondary Action (actions that result from other actions), and Appeal (creating design and motion that an audience will enjoy).

For actor training, we survey the work of Stanislavski, Meyerhold and Grotowski, along with more applied texts on actor training (e.g.(Alberts, 1997)). Probably no one had a greater influence on the art of acting in the last hundred years than Constantin Stanislavski, director of the Moscow Art Theatre and inventor of the "Stanislavski System", as the root of "Method Acting" in North America. Stanislavski wrote a trilogy

on acting technique: *An Actor Prepares* (Stanislavski, 1936), *Building a Character* (Stanislavski, 1949) and *Creating a Role* (Stanislavski, 1961). The first book focuses on the inner life of the character, the second deals with external representation (physical movement) and the third discusses how an actor can create a role. He argued that actors must *live* on stage. They must not merely try to mechanically reproduce a set of actions, but there must instead be emotional truth to what they do (Moore, 1984). We need to also imbue our virtual characters with this quality. While considering physical training important, he emphasized first focusing on methods to help an actor achieve psychological realism.

Vsevolod Meyerhold developed an exercise based form of actor training known as *biomechanics* (Law & Gordon, 1996). Sergei Eisenstein was his student during this time and developed a related method known as *Expressive Movement* (Law & Gordon, 1996). They argued that what an actor felt inside was not important if it was not communicated to the audience and counter to Stanislavski's inward focus, sought to increase an actor's physical vocabulary (Law & Gordon, 1996). They proposed that a highly trained actor could achieve emotional involvement through his movements (Moore, 1984).

Polish director Jerzy Grotowski formed the Theatre Laboratory in Poland with the goal of understanding the nature of acting. He drew widely on Soviet and Western theatre traditions, especially Meyerhold, as well as training methods used in the Orient (Grotowski, 1968e). Grotowski developed a training regime which focused on physical and vocal exercises, with the idea that actors approach movement ideas through their body (Tarver & Bligh, 1999). By repeatedly participating in a set of exercises, normally in silence, the actor gains a greater understanding of the nature of movement by experiencing it through his or her body. He argued that man does not behave "naturally" in heightened emotional moments, so one must go beyond naturalism to reveal the deeper truth (Grotowski, 1968e).

The movement theorists include: Francois Delsarte, a 19th century French theoretician whose work was influential in actor training and the development of American modern dance (Shawn, 1963); Barba and Savarese, who developed the field of *theatre anthropology* to study the art of the performer; and Rudolf Laban and his collaborators who developed Laban Movement Analysis (LMA). LMA offers a systematic study of expressive aspects of movement, divided into Body, Effort, Shape and Space. Body includes structural aspects of movement related to the anatomy of the body and how motion passes through the body. Effort refers to a person's attitude of indulging or resisting four movement qualities: Weight, Space, Time and Flow. Shape describes the process of change between poses as well as particular poses a character assumes. Space relates a character's movement to external pulls in the environment.

The LMA system aims to describe movement without defining a particular meaning for it. In other words, it aims to describe what the mover is doing, rather than applying an interpretation as to what emotion that movement suggests or what impression it should make on an observer. Delsarte's work on the other hand often maps movements to specific meanings. Some of these mappings will be included in the discussion below, but without careful experimental validation, are best viewed as an initial, potential interpretation rather than an immutable truth.

Motion Qualities

This section will review the key aspects of movement discussed in the literature. After a brief discussion of general movement principles, the discussion will be organized around four aspects of movement I term: Shape, the poses adopted by a character; Transitions, all the transients aspects of movement as a character moves from pose to pose; *Timing; and Phrasing*, how motion qualities are layered and combined.

To begin, it is worth noting that the motion we want from our animated characters may be different from the motion we experience in daily life. Barba argues that, "[t]he way we use our bodies in daily life is substantially different from the way we use them in performance." (Barba, 1991b, p.9), suggesting that "[w]hile daily behaviour is based on functionality, on economy of power, on the relationship between the

energy used and the result obtained, in the performer's extra-daily behaviour each action, no matter how small, is based on waste, on excess." (Barba, 1991a, p.55). The purpose of stage movement is to infect the audience with emotion (Eisenstein & Tretyakov, 1996) and it is generally when the attributes of an actor's movement are out of the ordinary, that they will have the greatest significance for the audience (Alberts, 1997).

Driven by the need to clearly communicate with an audience, performance movement is based on two basic principles: simplification (Lawson, 1957; Thomas & Johnston, 1981; Lasseter 1987; Barba, 1991b; Moore, 1984) and exaggeration (Thomas & Johnston, 1981; Lasseter 1987; Barba, 1991a). These two properties work together to clarify the meaning of a character's movement in the spectator's mind.

Simplification, also known as the "Virtue of Omission" (Barba, 1991b), works to bring focus to certain elements of a character's movement by eliminating extraneous movements (Barba, 1991b). Traditional animation principles suggest having a character only do one thing at a time so that the action reads clearly (they also suggest having one action bleed into the next for fluidity) (Thomas & Johnston, 1981; Lasseter 1987). In her summary of Stanislavski's teachings, Moore suggests that "[e]very form of expression must be simple and clear", with an emphasis on precision (Moore, 1984, p.54). All this brings a focus on communication, and arguably clarity, to performance motion that is often lacking in the movements of daily life.

Once a movement has been simplified, it is exaggerated to ensure that its meaning is conveyed to the audience. Thomas nicely summarizes the interplay of simplification and exaggeration as follows:

As artists, we need to find the essence of the emotion and the individual who is experiencing it. When these subtle differences have been found, we must emphasize them, build them up and at the same time, eliminate everything else that might appear contradictory or confusing. (Thomas, 1987b, P.6)

Movements should never be vague; audiences demand motions which they can follow (LeCoq, 2002).

Implementations

Applying these ideas to virtual characters suggests that verisimilitude of daily life may not be the ultimate goal. Rather, movement more focused on clear expression may be more effective in virtual worlds and more consistent with other performance contexts.

SHAPE

The shape category gathers properties that refer both to a pose at an instant in time and how these poses change.

EXTENSION

Extent or extension refers to how far an action or gesture takes place from a character's body. It can be thought of as how much space a character is using while completing an action. Laban (1988) refers to the area around a person's body as the *Kinesphere* and defines three regions within it: the near region, anything within about ten inches of the character's body, is the area for personal, intimate or perhaps nervous actions; the mid area is about two feet from the person's body and this is where daily activities take place, such as shaking hands; the area of far extent has the person extended to full reach. It is used for dramatic, extreme movements and in general is used more on stage than in daily life.

Delsarte suggests that excitement, explosive anger, strong and violent emotions that are aggressive all act to expand action (or increase extent) (Shawn, 1963). Thought, meditation, concentration, fear, suspicion and repulsion contract a body's movements. Normal emotions and gestures are in-between. He also suggests that slow movements that emphasize vastness and grandeur are aided by full extension. On a related note, Stanislavski suggests that an actor must be decisive in his big movements (Stanislavski, 1949).

Implementations

Several computational models have implemented control over extent, such as the EMOTE model based on Laban Movement Analysis (LMA) (Chi, Costa, Zhao, & Badler, 2000), Hartmann et al.'s (Hartmann et al., 2002, 2006) model based on social psychology (it is one dimension of their six dimensions of expression) and my previous work on motion editing (Neff & Fiume, 2003). All of these models scale the desired position of the hands relative to the body. They also include control over the swivel angle, defined by a rotation along the axis running from the shoulder to the wrist. This controls how close a character's elbows are to his sides and impacts his overall size.

BALANCE

Balance adjustments can move a character from being stably balanced on both feet, to a single foot, to the very edge of balance and are fundamental to expressive movement. Indeed, Barba claims that the "dance of balance" is revealed in the fundamental principles of all performance forms (Barba, 1991b):

The characteristic most common to actors and dancers from different cultures and times is the abandonment of daily balance in favour of a 'precarious' or 'extra-daily' balance. Extra-daily balance demands a greater physical effort -- it is this extra effort which dilates the body's tensions in such a way that the performer seems to be alive even before he begins to express. (Barba, 1991c, P.34)

Such balance adjustments can work to intensify a motion. "A change of balance results in a series of specific organic tensions which engage and emphasize the performer's material presence, but at a stage which precedes intentional, individualised expression." (Barba, 1991c, P.35) Many performance traditions will impose physical constraints to make the balance task more difficult, for example binding feet or having a ballerina work on toe. Balance adjustments can activate chains of muscles that connect multiple segments of a person's body.

When we stand in daily life, we are never still, but rather are constantly making small adjustments, shifting our weight to the toes, heels, right side, left side, etc. These movements should be modeled and amplified in performance (Barba, 1991b). A proper balance adjustment can even give a static pose a sense of motion:

The performer's dynamic balance, based on the body's tensions, is a balance in action: it generates the sensation of movement in the spectator even when there is only immobility. (Barba & Savarese, 1991, p.40)

Being off balance also reflects on the action that has just been completed (Tarver & Bligh, 1999).

Improved control of balance is part of the actor training of Meyerhold, Grotowski and Stanislavski (Law & Gordon, 1996; Grotowski, 1968b; Stanislavski, 1936). Delsarte suggests that balance can create a mood of security and control; imbalance suggests insecurity, indecision, fear and worry (Shawn, 1963).

Implementations

Computational models of balance have often focused on static balance in which a character's center of mass must project to the support polygon defined by the perimeter of its feet (Wooten, 1998). We (Neff & Fiume, 2004, 2006) presented a kinematic model based originally on Wooten's controller (Wooten, 1998) and later extended to handle more complex adjustments (Neff & Kim, 2009). Wooten (Wooten, 1998) and van Welbergen et al. (Welbergen, Reidsma, Ruttkay, & Zwiers, 2010) have applied this to physically simulated characters. Other approaches (Tak, Song, & Ko, 2000; Tak & Ko, 2005; Shin, Kovar, & Gleicher, 2003) rely on the Zero Moment Point, which acts as a measure of dynamic balance and can be used to correct the balance of more rapid movements.

POSTURE AND POSE

Posture is one of the clearest indicators of both a character's overall personality and emotional state in a particular scene. Alberts (1997) suggests that posture is a combination of two components: the degree of tension displayed in the body and the overall body position. Body position includes standing, leaning, kneeling, sitting and lying down. Alberts proposes the following posture scale: hunched, stooped, slumped, drooped, slouched, sagging, tired, relaxed, straight, upright, uptight, erect and over-erect (at attention). This range runs from a tired old man to a rigidly erect army officer.

Shawn argues that one of the main contributions of Delsarte was realizing that the torso is the main instrument of emotional expression (Shawn, 1963). It was for this reason that modern dance moved away from the stiff and fixed spine that is traditional in ballet.



Figure 9-1: Venus de Milo

Delsarte suggested that the part of the torso that a person habitually holds forward is a strong indicator of what kind of person they are (Shawn, 1963). If they hold their chest high, this indicates self-respect and pride. If their abdomen is protruding, this indicates animality, sensuality and lack of bodily pride. A normal, balanced carriage will have the middle zone of the abdomen carried forward and the chest and abdomen withdrawn. This triad can be augmented by considering people who carry their head forward, normally indicating a mental or academic disposition.

The shape of the spine in the coronal plane is also important. The "S" curve or "Beauty Line" involves the legs, torso and neck in making a large S curve with the entire body. It is a key pose in Indian dance, where it is called *tribhanga*, meaning three arches. It was also prominent in ancient Greek sculpture, the Venus de Milo offering a clear example [Figure 9 1], and was taken up by Florentine sculptors in the 14th century (Barba & Savarese, 1991). This also serves to illustrate the importance of the interplay between the legs, torso and neck.

Laban suggests that there are three principal components of trunk movement: rotational movement about the length of the spine; “pincer-like” curling from one or both ends of the trunk and “bulge-like” shifting of the central area of the trunk out of its regular position (Laban, 1988).

The torso can be expanded, contracted or relaxed. According to Delsarte, expansion indicates different degrees of excitement, vehemence and power of the will. Contraction indicated different degrees of timidity, pain, effort or convulsion of the will. Relaxation indicates different degrees of surrender, indolence, intoxication, prostration and intensity of the will (Shawn, 1963).

The legs of a character have a functional role to play in supporting it, which limits their expressive range. Nonetheless, stance is very important (Shawn, 1963). The main sources of variation in the legs are the width of the stance, the bend in either knee, whether the legs are turned out, in or straight and whether there is a twist in the pelvis. Stanislavski argues that the legs should be turned slightly out; rising on one’s toes suggests flight; feet and toes modulate jerkiness and give a quality of smoothness and gracefulness to motion (Stanislavski, 1949).

The arms and hands are used to create a wide range of motions. Delsarte refers to the shoulder, elbow and wrist joints as thermometers because he feels they indicate *how much* rather than *what kind* of expression (Shawn, 1963). Raised shoulders act to strengthen any action, the more they are raised, the stronger the action. He argues no intense emotion is possible without the elevation of the shoulders, or forward contraction in the case of fear or backward pull to show aggression or defiance. “The elbow approaches the body by reason of humility, and moves outward, away from the body, to express pride, arrogance, assertion of the will.” (Shawn, 1963, p.41) Elbows within the column of the body denote a lack of self-respect. Finally, a not rigid, but strong wrist indicates a strong, healthy condition. A limp wrist indicates weakness or a devitalized condition. A sharply bent wrist indicates a crippling influence.

Wrist movement can also add definition to a gesture (Lawson, 1957). Stanislavski argues that the arms should neither hang in-front nor behind the body, but at the actor’s side. Elbows should turn outward, not inward, but this cannot be excessive (Stanislavski, 1949).

Poses can be either symmetric or asymmetric. Lasseter (1987) recommends avoiding perfect symmetry (twinning) as this generally looks unnatural. This is particularly true with regards to how the pose reads in the 2D image of the animation. Grotowski argues “if something is symmetric it is not organic!” (Grotowski, 1968b, p.194). Asymmetric poses generate tension through opposition, whereas symmetric poses lack opposition and give balance (Barba, 1991a).

Within the LMA Shape category, *Shape Qualities* describe how a pose can change along the cardinal axes and capture an overall movement tendency. Vertical movement can be either *Rising* if the pose stretches upwards, or *Sinking* for downward movement. Forward movements are *Advancing* and backward movements *Retreating*. Horizontal movements that go sideways out from the body are *Spreading* whereas those that move inwards and cover the chest are *enclosing*. *Gathering* and *Scattering* are related but slightly more general concepts. Motions in which a person wraps their arms around space and brings it to them (think of a hug) are *gathering*. On the other hand, if the character starts with her hands near her middle and thrusts them out and away from her body to the sides (picture spreading seeds onto a field), this is a *scattering* gesture. Delsarte observed this same pattern. Generally speaking, scattering actions suggest openness, sharing and an external focus. Gathering actions suggest the character is closed, coveting or tormented and internally focused. Open and closed static postures have similar connotations. Posture changes are done relative to a character’s body attitude, the habitual default body configuration the character holds.

Closely tied to posture, a commonly referenced (Law & Gordon, 1996; Tarver & Bligh, 1999) principle of effective movement is *full body engagement*, which indicates that the whole body should be engaged in all movements. Grotowski (1968b, p.193) writes:

Our whole body must adapt to every movement, however small....If we pick up a piece of ice from the ground, our whole body must react to this movement and to the cold. Not only the fingertips, not only the whole hand, but the whole body must reveal the coldness of this little piece of ice.

Full body engagement acts to clarify and emphasize a movement.

The literature offers little guidance on how to actually achieve full body engagement. One potential starting point is the LMA Body concept of *Patterns of Total Body Connectivity* (PoTBC). Emerging out of work developed by Laban's student/collaborator Irmgard Bartenieff, as well as work by Karl and Berta Bobath, Bonnie Bainbridge Cohen and Peggy Hackney, PoTBC provide an ordered set of patterns for organizing overall body activity that follow the developmental stages of humans (Hackney, 1998). The first pattern is the expansion and contraction of *Breath*. This can be divided into three dimensions of torso movement, lengthening and shortening in the vertical dimension, bulging and hollowing in the sagittal and widening and narrow in the horizontal. The next pattern, *Core-Distal* involves movements of the six limbs (arms, legs, head and tail) from the core out distally, and back in towards core; connecting core and distal. The *Head-Tail* pattern explores connectivity through the spine. *Upper-Lower* involves coordinated up and down movements of the arms and legs and can generate the first stages of crawling. *Body-Half* movements divide the body along the sagittal plane and one half stabilizes while the other half is mobile. Finally, the *Cross-Lateral* pattern features diagonal connections from one arm through to the opposite leg. It is the pattern behind walking.

Another organizing principle for full body movement is the idea of *Posture-Gesture Mergers* (PGM), developed by another of Laban's student/collaborators, Warren Lamb (1965), (Lamb & Watson, 1979). Gesture is defined as some movement of a part of the body (hands, arms, head, etc.). Posture is defined as a movement of the entire body. A posture-gesture merger occurs when the quality of the movement is the same for both the posture and the gesture and synchronized in time. Here "Quality" is defined in terms of the Effort and Shape Qualities of Laban Movement Analysis. The qualities need not overlap for the entire gesture, but there could be a partial PGM for a portion of the gesture. Lamb considers PGM a fundamental aspect of human movement and the particular patterning of PGMs to be a unique part of a person's movement style.

Implementations

When compared to the attention paid to arm gestures, there has been relatively little work on developing effective models of posture and torso movement. The expressive importance of the arm swivel angle has been recognized by several researchers, for example, in the EMOTE model (Chi, Costa, Zhao, & Badler, 2000), in our previous work (Neff & Fiume, 2004, 2006) and the work of Hartmann et al. (Hartmann, Mancini, & Pelachaud, 2006). This is an important control for any character system.

The EMOTE model (Chi, Costa, Zhao, & Badler, 2000) includes an implementation of Shape Qualities which deform the torso. They define a maximum orientation for each DOF in the spine, neck and collarbones for each movement quality (e.g. Rising). User parameters control the interpolation between these values and a neutral pose.

In previous work (Neff & Fiume, 2004, 2006), we developed a posture model that allowed a particular shape to be specified for the torso (e.g. a hunched posture, or the S beauty curve seen in the Venus de Milo) in combination with a desired balance point. In satisfying reach constraints on the arm(s), the system could change the degree of the shape, but its form would be maintained. This work illustrated the expressive importance of posture variation and different types of torso shaping, illustrating that a wide range of poses may look “natural”, but they will communicate different messages.

Data-based approaches to inverse kinematics (e.g. Rose III, Sloan, & Cohen, 2001; Grochow, Martin, Hertzmann, & Popović, 2004) work off either a motion clip or complete motion library and then find output poses that are both similar to these samples and satisfy end effector constraints. These methods offer an approach for generating realistic, full body poses. For character design, this shifts the problem from needing to determine the correct parameters to use in a model to deciding on the correct input motion to use to build the data-based algorithm in order to generate appropriate poses for a particular character.

Breath is an important component of torso change that has a strong expressive impact. This has seen limited attention in virtual character work, but hopefully this will change with the recent development of CG models for breathing (e.g. Zordan, Celly, Chiu, & DiLorenzo, 2004; Kider Jr, Pollock, & Safonova, 2011). Breath can support and coordinate with movement of the limbs. For example, the concept of Shape Flow Support in LMA (also called Breath Support) describes how the fluid nature of the torso can be engaged through breath to combine with the movement of the limbs in integrated, full body movements. The full set of PoTBC patterns offer a potential framework for generating full body motion.

SHAPE OVER TIME

Disney animators considered *squash* and *stretch* to be the most important movement principle (Thomas & Johnston, 1981; Thomas, 1987a). Only the most rigid objects do not deform when they are moved (Lasseter 1987) and as Thomas observes “...all living flesh is subtle and stretches or bulges or sags or becomes taut in reaction to the forces working on it” (Thomas, 1987a, p.23). Deforming their characters and objects as they animated became essential in order to give them a sense of life. Lasseter (1987) points out that hinged objects such as Luxo can squash and stretch without deforming. This of course applies to the human skeleton as well, for example, consider the volume changes in gathering and scattering movement or extension changes. Squash and stretch is also particularly important for facial animation (Lasseter 1987).

Recoil is one of the most frequently cited movement properties (Eisenstein & Tretyakov, 1996; Barba, 1991a; Lasseter 1987; Thomas & Johnston, 1981; Laban, 1988; Eisenstein, 1996; Taylor, 1999; Shawn, 1963). In its most basic form, recoil involves first making a movement in the opposite direction of the intended movement, followed by the intended movement itself (Eisenstein, 1996). It creates a negative space into which the motion can travel. Recoil serves to underscore and accentuate a movement (Eisenstein & Tretyakov, 1996; Eisenstein, 1996) and is one form of the traditional animation principle of Anticipation. Recoil also allows the momentum of an action to be built, as with the backswing before a punch. This also relates to phrasing, discussed below.

The path a movement takes in space can also have an important expressive impact. Gathering vs. Scattering movements offered an example of this. Within the LMA Shape category, Modes of Shape Change describe different ways a person can interact with their surroundings. *Shape Flow* movements are self-focused and connect with breath and the inner fluid nature of the body (think of a tremor or a dance where the person’s focus is on feeling the connections in their own body). *Directional* movements connect the character to the environment, either with straight, linear movements (*Spoking*), such as pointing at an object, or rotational movements (*Arcing*), such as waving. *Carving* describes three-dimensional movements that cut through space in voluminous way, for instance to describe the shape of a large ball.

The Space component of LMA further explores how a person connects to their environment. *Central Spatial Tension* involves radial pulls from the character's center out to the periphery of the Kinesphere. In *Peripheral Spatial Tension*, the movements of the hands or feet maintain a fixed distance from the body, for example envision someone running her hands along the edge of an imaginary cylinder centered at the her body. *Transverse Spatial Tension* involves movements that travel between the center and the periphery, but without a radial orientation, for example grabbing an object in front of you and swiping it back, past your side.

Spatial pulls may also be dimensional, aligning with the horizontal, vertical or sagittal (forward-back) axis. Combining two pulls gives movements in a plane and combining three pulls gives full, three dimensional movement. Ordered patterns of these spatial pulls are developed in Laban's concept of Space Harmony, defining sequences of spatial pulls known as scales which a person moves through, but that lies beyond the scope of this article.

Directionality can give movement a clear sense of focus. Describing one of his actors, Grotowski says "All his movements have a well-defined direction that is followed by all the extremities and, on closer observation, even by all the muscles" (Grotowski, 1968b,p.186). This leads to a decisive and clear movement piece.

Implementations

There has been limited implementation work for much of this area. There are numerous deformation techniques that allow a character mesh to be varied over time, but outside of muscles and clothing, less work that explores what types of variations are effective for virtual characters. Recoil is closely related to the traditional animation concept of *anticipation*. A simple way to implement this in pose based approaches is to adjust the interpolation function to first have a character move away from a target pose before reversing directions and moving towards it (Chi, Costa, Zhao, & Badler, 2000; Neff & Fiume, 2005). IK provides a way to specify a motion path through space, but I am unaware of work that uses this to organize the movement of the full body.

TRANSITIONS

Transitions include all the transient aspects of movement as a character moves from pose to pose.

MOVEMENT FLOW

Laban (1988) suggest that movement can flow continuously, be intermittently interrupted, yielding a trembling kind of movement, or stopped yielding a pose. It is worth distinguishing between a motion that is paused (Laban, 1988; Tarver & Bligh, 1999) or suspended (Alberts, 1997) and one that is stopped. When a motion is paused, there is no perceptible loss of intensity nor break in intention. When a motion is stopped, the energy of that motion has been lost and the actor's focus is no longer on the completion of a motion. It cannot be seamlessly continued with the same intensity (Tarver & Bligh, 1999). Motions can also be either complete or incomplete (Tarver & Bligh, 1999). Many actions in daily life are incomplete. They are interrupted before they reach their natural conclusion. Being able to break an action before completion can have a powerful impact as it can be a strong indicator of a character's internal mental process.

Stanislavski related flow to how energy moved through the body, "...external plasticity is based on our inner sense of the movement of energy" (Stanislavski, 1949, p.67). A smooth and regular flow of energy gives a smooth, measured and elastic step. Energy in jerks creates an uneven, choppy gait. Stanislavski told his actors that flow must be controlled and to think of a bead of mercury that they are consciously moving through their veins. Creating an endless, unbroken line with this bead will give smooth, flowing movement (Stanislavski, 1949). This idea relates closely to the chains of connectivity underlying Patterns

of Total Body Connectivity. It should be noted that developing a sense of flow is very closely related to the use of successions discussed with phrasing.

Implementations

I am aware of little work that explicitly addresses these concepts, although models for succession and physics-based tension change (discussed later) capture some aspects of flow. Disrupted flow still needs a precise, computationally definition. The ability to pause or stop a movement midstream is a useful feature for designers of virtual worlds to include.

MOTION ENVELOPE

The *motion envelope* describes the speed profile of a movement over a transition; its patterning of acceleration and deceleration. For example, some movements will start slowly and end quickly while other movements will do the opposite. Disney animators found it effective to have the bulk of footage near extreme poses and less footage in between in order to emphasize these poses (Thomas & Johnston, 1981; Lasseter 1987) and referred to this as *slow in, slow out*. In computer animation, an ease-in, ease-out curve provides the same effect, transitioning most quickly during the middle of the movement and slowing at the beginning and end. Animators will often go beyond this to create more varied control of timing, for instance using just an ease-in curve or just an ease-out curve to transition between poses.

Implementations

Control of the motion envelope is widely supported, most often by controlling the tangents of splines that are used to control the interpolation between poses. The double interpolant method first proposed by Steketee and Badler (Steketee & Badler, 1985) decouples the path through space from the timing of the motion. This is very useful for allowing expressive variation in timing without altering a motion's path. Tools such as tension, continuity and bias splines (Kochanek & Bartels, 1984) offer additional flexibility by allowing control over the shape of the interpolating curve. These techniques are key components in the EMOTE model (Chi, Costa, Zhao, & Badler, 2000) and Hartmann et al.'s style model (Hartmann, Mancini, & Pelachaud, 2006), and we provide comparable controls in (Neff & Fiume, 2005).

EFFORT

The Effort category of LMA is probably the one most frequently applied to character animation. It describes a person's inner attitude towards four qualities that are either indulged in or resisted, giving a bipolar scale for each.

Weight Effort (Strong - Light) refers to the person's attitude towards the use of force. If they are moving very forcefully (e.g. stomping up stairs), this is *Strong Weight*. If they are moving with gentleness, carefully regulating the amount of force they use, this is *Light Weight*. A physically heavy person may move in a Light way and vice versa.

Time Effort (Sudden - Sustained) describes changes in timing compared to surrounding movements, rather than overall speed. If a movement is very rapid compared to the surrounding movements, this is *Sudden Time*. If a movement is prolonged, this is *Sustained Time*. A person might have a sense of urgency or wish to linger.

Space Effort (Direct - Indirect) relates to how a person focuses their attention. If they are focusing on a particular point, this is *Direct Space Effort*. If they are attuning to the entire space, this is *Indirect Space Effort*. Movements of the rest of the body will generally reflect this focus, for example, providing a clear sense of directionality towards a single point of focus, such as staring, pointing and marching towards a misbehaving child spotted across a room, or moving in a way that attunes to the global space, such as maintaining awareness of a large group of children at play across a field.

Flow Effort (Bound - Free) describes how controlled someone's movements are. *Bound* movements are tightly controlled, precise, possibly stiff, whereas *Free* movements are loose and uncontrolled.

A movement may contain any subset of the qualities (e.g. there might be no aspect of Time present) and it is rare for all of these qualities to be present at once. Pairs of qualities combine to form an Effort State and triples form Effort Drives. For example, the Action Drive combines Weight, Time and Space, with evocative names given to each combination of poles. A *punch* is combination of Strong Weight, Sudden Time and Direct Space, whereas a float is a combination of Light Weight, Sustained Time and Indirect Space.

Implementations

Researchers have long sought to develop a computational representation for Effort because it encapsulates an important range of expressive variation. The EMOTE model (Chi, Costa, Zhao, & Badler, 2000) provides a procedural implementation based on interpolating key poses to generate motion. It adjusts the interpolation space that is used to move between poses (end effector, joint angle, or elbow), as well as the parameters of the interpolation functions, both to vary the path through space and adjust the timing. It also adds flourishes that add extra wrist bend or sinusoidally deflect the elbow to evoke particular Effort qualities.

Torresani et al. (Torresani, Hackney, & Bregler, 2007) take a data driven approach and capture motion of trained dancers performing different Effort constellations. From this, they learn an interpolation function that allows them to vary between the various Effort qualities.

TENSION AND RELAXATION

The interplay of tension and relaxation is another widely cited movement property (Dorcy, 1961; Laban, 1988; Shawn, 1963; Lawson, 1957; Barba, 1991a), closely related to the Flow Effort (Free to Bound) dimension in LMA. Tension and relaxation naturally interleave: there must first be relaxation in order for there to be tension and tension is followed again by relaxation. There is a consequent ebb and flow of energy that accompanies changes in tension (Shawn, 1963). This also relates to the preparation, action, and recuperation pattern of phrasing discussed below.

Tension changes can take place through the entire body or a tiny part. They can occur suddenly or gradually and there can be spasmodic changes back and forth (Lawson, 1957). A rise in tension can serve to accent a movement (Laban, 1988). For example, physical or emotional pain can be shown by spasmodic contractions of muscles, followed by relaxation as the pain eases (Shawn, 1963).

Stanislavski stresses the importance of an actor being relaxed and avoiding tension in his body (Stanislavski, 1936; Stanislavski, 1949; Moore, 1984) arguing "*You cannot ... have any conception of the evil that results from muscular spasm and physical contraction.*" (Stanislavski, 1936, p.91) An actor must learn to identify the sources of tension in his body and relax them (Moore, 1984). Stiff arms and legs give the body a wooden quality, looking like a mannequin. "The resulting impression is that the actor's soul is likely to be as wooden as his arms. If you add to this a stiff back, which bends only at the waist and at right angles, you have a complete picture of a stick. What emotions can a stick reflect" (Stanislavski, 1936, p.102).

Implementations

We provided tension control using a physical simulation approach in which a variant of a proportional derivative controller is used as a simple model of muscle (Neff & Fiume, 2002). This is a first order approximation of real muscle, representing it as a spring and damper. The gain on the spring term in a PD controller regulates the amount of tension in the motion. Reducing the tension is useful for making more floppy motion, for example as a wrist follows the movement of an arm, and pendular movement when

an arm drops to a character's side. Tension control also determines how forces transfer through the body, allowing a character to look very rigid, or relaxed and loose.

WEIGHT

It is critical that characters have a sense of weight (Thomas & Johnston, 1981; Thomas, 1987a, Appia, 1962 (original 1921), fifth edition 1982; Laban, 1988). This creates the physicality necessary for realism by providing the sense that the character is actually inhabiting and interacting with his/her environment. Thomas and Johnson suggest that it is an inability to correctly capture a sense of weight that makes cartoon characters lose credibility when viewed next to live action (Thomas & Johnston, 1981;).

Laban relates weight to the use of muscular energy or force to either move a weight or to react to a resistive force (Laban, 1988). Weight can come either from the weight of a body part to be moved or from an object being moved. Resistance can be internal, coming from the antagonistic actions of the character's own muscles and reflecting internal conflict, or external, coming from other objects or people. Resistance may involve strong, normal or weak muscular tension.

Implementations

An accurate sense of weight is probably the biggest win for simulation based approaches to character animation. There has been a great deal of research in this area over the past 25 years. We are starting to see these approaches applied for virtual worlds, for instance in the work of van Welbergen et al. (van Welbergen, Reidsma, Ruttkay, & Zwiers, 2010).

PHRASING

Phrasing deals with issues ranging from how joint activations are ordered in a particular movement to how an entire motion sequence is put together.

JOINT ACTIVATION ORDER

Successions deal with how a movement passes through the body. Rarely will every limb involved in a motion start and stop at the same time. Delsarte defined two types of successions: true or normal successions and reverse succession (Shawn, 1963). In a normal succession, a movement starts at the base of a character's torso and spreads out to the extremities. In a reverse succession, the movement starts at the extremities and moves in towards the centre of the character. Shawn claims that the conscious use of successions was fundamental to the development of modern dance (Shawn, 1963).

Successions are part of the "Follow Through and Overlapping Action" principle of Disney animation (Lasseter 1987). Thomas and Johnson write:

Our most startling observation from films of people in motion was that almost all actions start with the hips; and, ordinarily, there is a drop -- as if gravity were being used to get things going. From this move, there is usually a turn or tilt or a wind up, followed by a whiplash type of action as the rest of the body starts to follow through....Any person starting to move from a still, standing position, whether to start walking or pick something up, always began the move with the hips. (1981, p.72)

This also emphasizes the role of weight shifts discussed earlier and introduces the phrasing concept of initiation, where a particular body part begins a movement. Grotowski similarly argues that "The driving impulse, however, stems from the loins. Every live impulse begins in this region, even if invisible from outside." (Grotowski, 1968b, p.191), again reflecting the outward flow of movement consistent with a

normal succession. Stanislavski also gives examples of exercises designed to teach the use of successions in order to increase fluidity (Stanislavski, 1949).

The Body component of LMA defines three forms of movement sequencing (Hackney & Meaden, 2009). In *simultaneous* movements, all body parts start and stop at the same time. In successive motions, the movement travels from one body part to the next adjacent body part (e.g. collar bone to shoulder to elbow to wrist). Finally, in sequential ordering, movement jumps from body part to body part (e.g. left elbow to right elbow, or wrist to shoulder).

Implementations

Control based on IK provides simultaneous movement because all joint angles in the kinematic chain are updated at the same time. It is for this reason that animators will often avoid using IK in favor of the greater control over phrasing provided by FK (Benseghir, 2007). Successions have been explicitly represented in my work on motion editing (Neff & Fiume, 2003) and are part of the Hartmann et al. style model (Hartmann, Mancini, & Pelachaud, 2006). They can be simply implemented by offsetting the start and end time of each joint in a motion, moving from the root out to the extremities. Adding flourishes, such as an accompanying flexion and extension of the wrist, can aid the effect (Chi, Costa, Zhao, & Badler, 2000). Coleman et al. (Coleman, Bibliowicz, Singh, & Gleicher, 2008) introduce “staggered poses”, a representation for this offsetting of the motion of different joints, along with related editing commands. Adding successions to motions can increase a sense of flow.

PHRASES AND PHRASING

A *phrase* is defined as “any movement with a through line containing a beginning and an end” (Hackney & Meaden, 2009). It could thus be viewed as representing a “unit” of movement which may contain multiple actions. The phrase definition places no particular limit on duration. A phrase could be a sub-second flick or a kilometre long run if it is done with a single intent. The changes between phrases are marked by changes in intent or focus and can be somewhat difficult to identify. Individuals may have a preference for a particular phrase length and use this often in their movement (cf. tempo-rhythm).

Phrasing can be viewed as the process of patterning over time. It is the “manner of execution or the way in which energy is distributed in the execution of a movement or series of movements.” (Yvonne Rainer cited in Maletic, 2000).

A movement phrase can be broken into a series of phases (Hackney, 1998). These include, in order:

1. *Inner preparation*, the internal thought process that precedes the movement when the brain formulates a motor plan.
 2. *A moment of initiation*, when the mover begins the motion. Action pathways are setup during this phase. The part of the body that initiates movement should be noted.
 3. *Main action/Exertion* includes the primary action of the movement.
 4. *Follow-through* carries the momentum of the body onwards once the main action has been completed.
 5. *Recuperation* allows the mover to recover from the exertion of the phrase.
- Phrases are often preceded and followed by momentary pauses.

Emphatic phrases have a point of emphasis during the phrase, for example a Sudden wrist flick in the middle of a movement. Emphasis is generally notated as being at the beginning, middle or end, although more complex, multi-emphasis phrases are possible. Beginning emphasis could occur during initiation, middle during the main action and end emphasis either at the end of the action or in the follow-through phase, if it's present. Non-emphatic phrases are even throughout, such as a move in Tai Chi.

Maletic (2000) adds three additional types of phrasing. *Accented Phrasing* consists of a series of accents which together form a sequence. These involve exertions of energy followed by long or short periods of stillness. *Vibrating Phrasing* consists of a series of “sudden, repetitive movements”. *Resilient Phrasing* “creates several rebounding, resilient movements together forming an entity”.

Phrasing often involves changes in Effort qualities. Effort can be used to show emphasis in three ways.

Loading adds an additional effort dynamic to the movement. The *intensity* can be changed by increasing the “volume” of the effort qualities. Finally, in a *change of effort*, the effort qualities present are changed, often by reversing the factors (e.g. from Light Weight to Strong Weight). Accents can be added to movements through a combination of Weight and Time Effort (Hackney & Meaden, 2009). A Light accent uses Sudden Time and Light Weight. A Strong accent uses Sudden Time and Strong Weight.

Maletic also observes that phrases can be layered in time and across different body parts. In *consecutive* phrasing, one phrase completes and then the next begins. *Simultaneous* phrasing occurs when different parts of the body execute different phrasing patterns (e.g. middle emphasis or beginning emphasis) at the same time. In *overlapping* phrasing, one part of the body starts a new phrase while another part of the body is completing the previous phrase. This corresponds to the animation principle of *overlapping action*. As Disney once instructed his animators, “Things don’t come to a stop all at once, guys; first there’s one part, and then another” (cited on p.59, Thomas & Johnston, 1981).

Implementations

Detailed computational models of phrasing are lacking. This is in part because there has been limited work focused on the composition of detailed movement sequences. LifeForms (e.g. (Bruderlin, Teo, & Calvert, 1994)) is a notable exception as a system that foregrounds the composition process. In gesture work, the preparation, stroke, retraction model has become common (e.g. Hartmann, Mancini, & Pelachaud, 2002), and this shows clear parallels to the phases of a movement phrase.

COMPOSING MOVEMENT SEQUENCES

Actions need to be given adequate time if the audience is going to follow the inner thoughts of the character. Delsarte argued that there is a sequence of perception, recognition and action that underlies movements (Taylor, 1999). Allowing time for these different phases can make the communication with the audience more clear. This relates to the more general form of the *anticipation* principle in traditional animation. It is important to give the audience hints as to what is coming so that they are prepared for it and will perceive it when it arrives (Lasseter 1987; Thomas & Johnston, 1981).

Lasseter (1987) argues that it is important to spend the correct amount of time on anticipation for an action, the action itself and then the reaction to the action (Lasseter 1987). Timing can be used to indicate if a character is nervous, lethargic, excited or relaxed (Lasseter 1987). In order to give a sense of life, it is also important to show character’s thinking (Thomas & Johnston, 1981) and time must be allotted to this in the animation.

Secondary action can be added to a movement sequence in order to strengthen and clarify the meaning of a sequence. This can include small actions like a character wiping a tear, shaking his head or putting on glasses (Thomas & Johnston, 1981), as well as physical reactions to a movement, such as the flow of long hair.

REACTIONS AND CHARACTER INTERACTION

For characters to appear real, it is vital that they react to both other characters and objects in the virtual world. Much actor training focuses on preparing performers to react fluidly and spontaneously to other actors and their environment. Grotowski (1968d, p.225) describes the process of acting as follows: “Something stimulates you and you react. That is the whole secret.” The main principle of Grotowski’s work is *via negativa*; a process of eliminating the blocks that are inhibiting the actor (Barba, 1968) so that an actor’s body can be free and completely responsive to stimuli. According to LeCoq (2002, p.10), “reaction creates action”. “There is no action without reaction” (LeCoq, 2002, p.89). Movement is often a reaction to various stimuli: those that are internal, from another character or from the environment. Our characters must both sense these stimuli and react to them.

Contact is Grotowski’s term for an awareness of other people, their actions and their moods. He argues that theatre is composed of elements of human contact; “give and take”. These are what define the score for the actor. “Take other people, confront them with oneself, one’s own experiences and thoughts, and give a reply” (Grotowski, 1968a, p.212). Contact between characters must be maintained during a performance. As one actor makes small changes to the set performance, the other actor should make adjustments as well and hence small changes to the performance should emerge from that contact (Grotowski, 1968d). Contact is important for maintaining believability. Stanislavski also emphasized the importance of an actor relating his behaviour to the other characters on stage. He must honestly absorb what they say and do and react to them (Moore, 1984). The inner and outer adjustments people make to one another Stanislavski terms *adaptation* (Stanislavski, 1936). In the animation setting, it is similarly important that characters are sensitive to each other’s behaviour and fit their actions to what the other characters are doing. They must have *contact* and *adaptation*.

Characters must also adapt to overcome physical obstacles (Moore, 1984). A character must perceive and interact with objects. He must treat them as if they are what he wants the audience to perceive them to be. It is important to assign meanings to objects and then show those meanings in movement. For instance, a drink might be wine or poison. The character’s movements should reflect which it is. (Moore, 1984)

Regulating behavior (e.g. gaze changes) by which a speaker maintains or gives up the floor helps determine turn taking in conversations and is another important aspect of interpersonal interactions (Alberts, 1997). It is often dropped in stage movement or animation as the interactions are preset and so there is no need for it. Adding regulating behaviour to a piece of performance motion, however, can help increase realism. It is even more important for spontaneous character/avatar interactions in which the conversational turn must be actively managed.

If two characters are placed in the same scene, a number of factors become important, such as:

How each character moves relative to the other character (e.g. do they mirror postures?), what changes they make in stance and posture, how they position themselves in space and their relative orientation. These not only speak volumes about the relationship between the characters, but also comment on the personality and inner state of each character individually.

Following Alberts, the amount of space around the body that a person considers to be private or personal varies a great deal from culture to culture (Alberts, 1997). In North America, personal space extends outwards from the body roughly three feet in all directions, which is more than most other cultures. The intimate zone extends to about eighteen inches. The social zone is about four to ten feet. Four to six feet is safe for informal conversation, six to ten feet is more suited for formal interactions. The kind of greeting someone makes when passing a friend on the street is a function of the distance at which they pass. If they

are more than about twelve feet apart, a wave is fine. Ten to twelve feet normally requires them to verbalize. Passing within six feet, they should generally enter into a conversation.

Eye gaze is an important factor in indicating both a character's interests and personality. The interpretation ultimately made of a character's gaze direction will depend very much on the overall context of the scene.

Implementations

Work on these ideas is occurring at two interacting levels: agent architectures that determine how a character should behave in a given interaction and lower level movement models that determine the details of a character's motion. Agent architectures are beyond the scope of this chapter, but they must deal with perception issues, especially when agents are interacting with a human, and decision making to plan appropriate responses. At the motion level, characters are beginning to adjust to their interlocutors through mimicry. (For an example of work on turn taking, see (Cassell, Torres, & Prevost, 1999)).

ACTION SELECTION

The problem of action selection – deciding what movements a character should make – is not the main focus of this chapter. However, since it is one of the main tasks in animation, some discussion is warranted. Moore goes so far as to suggest “[t]he creative process of an actor's work is choice of actions...” (Moore, 1984, p.56).

The rule of simplification applies to action selection and restraint is important (Stanislavski, 1949) as everything that happens on stage must have a purpose (Stanislavski, 1936). Complex human psychological life should be expressed through simple gesture (Moore, 1984). Stanislavski writes “Unrestrained movements, natural though they may be to the actor himself, only blur the design of his part, make his performance unclear, monotonous and uncontrolled” (Stanislavski, 1949, p.69).

The actions performed must relate to the inner life of the character, or they will lack meaning (Stanislavski, 1949). Stanislavski's work allows an actor to develop the proper inner process, from which the outer expression will flow (Moore, 1984). Every psychological aim should be expressed physically and every action should have a psychological aim (Moore, 1984). Furthermore, gestures and movements must have concrete justifications. Otherwise, we are left with beautiful gestures with the “emotions of a fairy dance” (Grotowski, 1968c).

“Frequently physical immobility is the direct result of inner intensity, and it is these inner activities that are far more important artistically.” (Stanislavski, 1936, p.34) Stillness can denote inner emotional weight.

Action choice determines the type of character which is created. Different characters might share an objective, but they will choose different actions to achieve it. There should be a continuous line through a character's actions and these should build towards the superobjective; the overall goal of the character (Moore, 1984).

One of Stanislavski's fundamental principles is that a performer should never try to act a feeling.

Fix this for all times in your memories: On the stage there cannot be, under any circumstances, action which is directed immediately at the arousing of a feeling for its own sake. To ignore this rule results only in the most disgusting artificiality. When you are choosing some bit of action leave feeling and spiritual content alone. Never seek to be jealous, or to make love, or to suffer, for its own sake. All such feelings are the result of

something that has gone before. Of the thing that goes before you should think hard as you can. As for the result, it will produce itself. The false acting of passions, or of types, or the mere use of conventional gestures, -- these are all frequent faults in our profession. But you must keep away from these unrealities. You must not copy passions or copy types. You must live in the passions and in the types. Your acting of them must grow out of your living in them.” (Stanislavski, 1936, p.38, original emphasis)

Actions must arise out of a context. Trying to act an emotion without connecting it to the context of the story will make for empty gestures.

Grotowski makes a similar argument, saying that actors should not illustrate words, suggesting that a bad actor who is asked to act bored will try to show boredom. His actions and gestures illustrate the word. A man who is actually bored will be very active. Perhaps he will read a book, lose interest and put it down. Then he'll look for some food, but nothing tastes good today. Then maybe he'll try to have a nap, but be unsatisfied with this as well (Grotowski, 1968d). It is good to remember that behaviour is composed of small, logical, concrete actions (Moore, 1984).

Emotions should be made specific to a given character. Again, we can turn to Stanislavski:

Most actors do not penetrate the nature of the feelings they portray. For them love is a big and generalized experience.

They try immediately to ‘embrace the unembraceable.’ They forget that great experiences are made up of a number of separate episodes and moments. These must be known, studied, absorbed, fulfilled in their entirety. Unless an actor does this he is destined to become the victim of stereotype. (Stanislavski, 1949, p.272)

Emotions are shown through a number of movements that are customized to be meaningful for a given character in a given situation. Emotional truth lies in finding these correct actions and performing them appropriately.

When creating a particular character, it is important to avoid easy stereotypes. Stanislavski's description of an old man is illustrative of the dangers here. “[The joints of an old man] rasp and squeak like rusty iron. This lessens the breadth of his gestures, it reduces the angles of flexibility of his torso, his head. He is obliged to break up his larger motions into a series of smaller ones and each has to be prepared before he makes it” (Stanislavski, 1949, p.29). A young man might turn his hips 50-60 degrees while an old man moves 20 degrees and slowly. The tempo and rhythm of an old person's motions are slow and flaccid. Yet Stanislavski criticizes an actor that directly implements this: “You are keeping constantly to the same slow rhythm and pace as you walk to an exaggerated caution in your gestures. Old people are not like that” (Stanislavski, 1949, P.30). Old people will change their rhythm, have periods of preparation followed by periods of speed. At times they are limbered up and there is momentum to their movements. They prepare actions much more than the young. For example, when sitting down they will feel for the chair and prepare to sit, sit, pause and then finally lean back. Once seated, the difficult part is done. The person can show more vigor, but while seated and with a limited joint range (Stanislavski, 1949). There is a varied texture to the movement. The old man does not perform all motions in the same way. Also, notice that both the sequence of actions performed and the manner change when an old man sits down versus a young. The old man adds additional actions to reach for the chair seat and make sure he is positioned correctly. A structural change must be made to the motion in order to take these differences into account. Both how the motion is performed and what motions are performed must be changed when the character is changed.

Clichés should be avoided. Grotowski suggests that when a character says “What a beautiful day”, he should not always say it with a happy intonation nor “Today I am a little sad” with a sad intonation. These are clichés. Strive instead for what the character’s deeper intention is, what lies below (Grotowski, 1968d). To determine such deeper intentions, it is helpful to analyze the character’s larger life, to understand her goals beyond a particular scene and then use her actions in a particular moment to provide insight into the larger internal thoughts and motivations of the character.

Implementations

Action selection is as much, or more, a problem of AI as it is of animation. The AI work is beyond the scope of this chapter, but there is some particularly relevant work drawing from the arts literature that is worth mentioning. Part of Delsarte’s analysis is a set of suggestions on how particular poses convey emotions or other connotations. Some researchers have suggested that this may be particularly useful in virtual agent research as it provides a defined set of behaviors for a character to perform in order to achieve a given impact, which is what the agent designer is normally after. Marsella et al. (Marsella, Carnicke, Gratch, Okhmatovskaia, & Rizzo, 2006) explore Delsarte’s “Attitudes of the Hand”, which considers the “gesture cube”, an imaginary box placed in front of the agent, and suggests meanings associated with having the hand posed on each face of the cube. They perform perceptual experiments in which an agent moves to one of these faces and ask users to rate the impression, confirming that some, but not all, of Delsarte’s mappings appear to hold for virtual agents. Nixon et al. (Nixon, Pasquier, & El-Nasr, 2010) introduce DelsArtMap, a mapping between nine emotions and character poses, that allows a user to specify emotional intensity values and yields an output pose. The poses are based on Delsarte’s division of body part positions into three categories: excentric, normal or concentric. For the head, these can be thought of as away, neutral or towards and are applied to both the twist and up-down rotation, yielding nine combinations. Their system includes poses for the head, torso, legs and arms. In future work, they plan to experimentally validate these mappings.

Another pose-driven approach to animation, focused on supporting choreography, DanceForms (Calvert, Wilke, Ryman, & Fox, 2005; Wilke, Calvert, Ryman, & Fox, 2005) provides a way to go from a structured representation of movement to 3D animation. The system takes Labanotation as input, a method for notating dance that is comparable to a score for music and specifies poses at points in time, along with additional information about the nature of the movement. DanceForms resolves ambiguities in the notation and generates output 3D animation. While this work is aimed largely at supporting composition, it demonstrates the great difficulty of generating movement from an external specification. Even with a very detailed description language like Labanotation, ambiguity remains that must be resolved in order to generate appropriate motion. Indeed, the authors argue that “a recurring issue ... is the need for a unique, unambiguous way to represent human movement”[p.6]. Having such a precise movement language would be of enormous value.

3. SIDEBAR: SIMPLE TECHNIQUES FOR IMPROVING CHARACTER MOTION

I describe here a few simple computational methods that are derived from material in the arts, can easily be added to a computational model and, in my experience, improve the quality of animation.

The arms do not start at the shoulders. Arm movements should include the collarbones, and ideally, one should also mobilize the torso and whole body as part of a gesture (cf. Patterns of Total Body Connectivity and Posture Gesture Merger). A simple way to add collarbone movement is to map the angle of the collarbones to the height of the hand. Simple IK can be applied from the shoulder to the wrist and the

additional mapping will automatically raise the collarbones as the character raises his arm. Beyond this basic biomechanical connection, the collarbones are very important for showing emotional changes and opening and closing the torso.

The torso has a strong expressive impact on character motion. A simple, but surprisingly effective method for engaging the torso is to map the curvature of the spine to the motion of the arm so that the torso varies in unison with arm movement. Different types of curvature will read differently. For instance, a forward C curve in the sagittal plane can be used to create an old or tired character. A large C curve in the coronal plane (vertical plane in LMA terms) can be used to create a more happy go lucky character that sways from side to side. An S curve in the same plane can create a more sensual feel. For a more detailed discussion of how this can be implemented as a motion editing tool and ways to automatically extract these relationships, see (Neff & Kim, 2009; Neff, Albrecht, & Seidel, 2007).

The swivel angle can be defined as the rotation around an axis that runs from the collarbone to the wrist. It moves the elbow close to the torso or out from the character's side. As Delsarte observed, this has a strong impact on the perception of personality and emotional state. Allowing direct control of this parameter provides a useful expressive handle. Packages like IKAN (Tolani, Goswami, & Badler, 2000) implement this and are freely available.

Our work (Neff & Kim, 2009) also presents algorithms that provide efficient control over the lower body through specifying intuitive parameters: control over the balance point, pelvic twist, foot positions and knee bends. We find these parameters that have the most expressive impact on the pose of the lower body. Gaze behavior can contribute significantly to making a character appear as though he is thinking. IK applied to the head and neck provides a simple way to implement this. Looking up and to the left is often associated with thinking.

Providing direct control over the motion envelope has become a standard technique in animation tools through variation of spline tangents and should be supported in any virtual character application. It is important to allow control over where the velocity peak occurs in the motion and to support anticipation and overshoot effects.

Controlling the succession in a movement can be implemented by first solving for a full body pose and then offsetting the timing of each joint in the pose. For example, the shoulder could start a couple of frames after the collarbones, the elbow a frame after that, etc.

One of the main advantages of physically simulating a conversational character is that it provides an effective method for adding pendular arm movement to the character's motion when they drop their arm to their side (e.g. (Neff & Fiume, 2002)). This enhances the naturalness of the motion. Simulation also provides a way to capture the impact of momentum on a character's movement.

4. LOST IN TRANSLATION: CHALLENGES IN APPLYING ARTS MATERIAL COMPUTATIONALLY

Character animation for virtual worlds must generate the correct movements to express personality and mood, a goal often shared with the arts. Nonetheless, it is a challenge to directly apply lessons from the performing arts literature to automatic animation production for a number of reasons. First, much of the literature is meant for embodied performers who can interpret this material within their own physical

bodies and against their substantial experience as movers. Actors develop much of their knowledge of movement through physical exercises, as is routinely emphasized (e.g. (Stanislavski, 1949; Moore, 1984; Grotowski, 1968b). These exercises serve a range of purposes, from providing a way for an actor to investigate movement (Barba, 1968), to developing concentration and an ability to notice and react to external stimuli (Barba, 1968), to developing a sense of rhythm.

Actors can also tap their emotional memories. Only a living actor has the muscle memory of actions performed during an emotional crisis, illustrating the psycho-physical connection between the internal mental experiences of actors and their outward movements that is lacking in virtual characters. For example, Stanislavski considered *emotional memory* to be a very important source for an actor (Moore, 1984), suggesting that an actor must execute the correct physical action to relieve the emotion required for a scene. Grotowski also argued for the importance of drawing on specific, real, intimate experiences (Grotowski, 1968d). Our ability to recall emotions and find through our body correct actions for them is likely one reason why animators often work out scenes in front of a mirror or by videotaping themselves. They need to be able to see what their body decided to do (or what movement they subconsciously triggered).

A second challenge is that motion is very complex, occupying a high dimensional space, with somewhere between 40 and over 100 degrees of freedom required to specify a pose of the human body, depending on the amount of detail required. While these DOFs are not all independent, it remains a challenging specification task. Moreover, this level of detail is entirely different than what is required in the arts when describing ideas for performers that can interpret these against their own experience. Actors do not need an external representation of movement, whereas computer models need to generate an explicit and precise representation. Applying the arts material thus requires the establishment of a mapping between the literature and concrete, computational representations such as procedural algorithms or motion libraries. This can be a challenge as movement experts may talk in analogies or at a more general level of detail than the very fine-grained representation required computationally. The arts properties are not precisely defined, in a computer science sense, and determining definitions is a substantial challenge. Indeed, defining this mapping is equivalent to defining the complete, unambiguous language for movement that Calvert (Calvert, Wilke, Ryman, & Fox, 2005) argues is missing.

Even when movement qualities can be given a precise definition, it is difficult to know the correct movements to perform in order to generate a particular impression with an audience. This decision is highly dependent on context, which may include the role of the character, his environment, his current emotions, who he is talking to, events earlier in the conversation, etc. The mappings are generally not simple and not fixed. Earlier in the chapter, I made an effort to focus on the most concrete and easy to apply ideas from the literature, but it is a mistake to blindly apply these properties in a prescriptive way. They are not recipes that can be followed to give a specific result, but abstract principles that give insight to the nature of movement. As Shawn says,

We have to extract [the laws of Delsarte], make simple statements of them for study purposes; but in actuality, in the final use, a vast number of these laws are operating simultaneously and mutually modifying and affecting each other to produce complex yet seemingly simple results. (Shawn, 1963)

There is a level of artist interpretation that is fundamental to these principles: “[N]o two artists using the same principle would produce forms of expression identical with each other, or with anyone else.” (Shawn, 1963, p.26). LeCoq (2002) argues that there is generally not one meaning for a movement nor vice versa.

Finally, perhaps the biggest challenge is that these motion qualities are not easily separable nor necessarily orthogonal. As Shawn suggests above, many qualities are combined in a single piece of movement. The qualities interact with each other in generating a final impression, and related descriptive properties

may alter the same aspects of movement. There is also a many to one relationship between the terms and movement. While trained observers may agree that a particular movement contains a particular movement quality, for instance Strong Weight, there is a vast array of different movements that could also contain this quality. Many more details need to be specified to move from a description, such as “Strong Weight”, to a complete movement that realizes it.

5. STEPS FORWARD

Despite the challenges, the arts literature still provides very important guidance for creating effective virtual worlds. It provides a road map that illustrates which movement properties are important and must be included in any motion representation. It is a valuable resource for anyone developing character movement, regardless of the domain, and indeed, can support a range of applications. It indicates useful ways to edit motion capture, provides guidance on the range of motions that should be included in a motion library and also indicates the type of AI problems that will need to be solved to generate effective character motion. There are deep questions here, in terms of how movement should be varied to adjust to context, how to generate a particular character with a unique movement signature and how to decide the right actions to use in a given situation.

A great deal of progress has been made on showing how ideas from the arts can be implemented to improve virtual character motion. I think there are three areas particularly ripe for further exploration. Full body engagement is still lacking from most virtual character systems. It is common for the arms to be controlled independently of the rest of the body and this leads to unnecessarily stiff and robotic movement. Phrasing has only been lightly explored. It is a complicated topic, involving issues in animation, AI and motion perception, but better models of phrasing will likely be important in developing personal movement profiles for characters. Finally, virtual worlds need to start making better use of deformations for breath and other variations of the character’s mesh, ranging from muscle movement to dynamic effects. There has been significant research on this in the character animation community, but it has been slow to migrate to virtual worlds.

While it remains an open question as to whether procedural approaches are the best way to leverage off the arts material, or if learning approaches applied to motion data will provide greater strides, the literature offers value to either approach. It defines what matters in movement and can therefore be used as a measuring stick to evaluate various techniques. What set of movement qualities does a technique cover and what set does it leave out? How complete is any given model?

Perceptual experiments will likely gain importance as this work develops. They allow us to both test claims made in the literature and validate particular implementations of these ideas. Marsella’s (Marsella, Carnicke, Gratch, Okhmatovskaia, & Rizzo, 2006) pioneering work on testing a hand orientation mapping proposed by Delsarte is inspirational in this regard. Such efforts will need to be continued and refined to better understand the role that various components of motion play in generating a particular impression. It will also be important to be able to compare the output of various animation systems, both to ensure consistency and to better refine movement models by learning best practices.

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