Developing a Virtual Ballet Dancer to Visualise Choreography

R. J. Neagle, K. Ng and R. A. Ruddle
*ICSRiM and School of Computing
The University of Leeds, England
{royce,kia,royr}@comp.leeds.ac.uk

Abstract

This paper describes the development of a virtual ballet dancer that is designed to help visualise choreography. Recreating dance not only involves how to achieve the steps but also the quality of the movement to express emotions. The aim is to create a visualisation system that could be used to understand the choreography with expressive movement when resurrecting ballet scores. Real-time computer graphics are ideally suited to bridge the gap between written choreographic notation and performance, via the creation of a virtual dancer. In theory, a realistic virtual performance can be driven from a machine-readable version of dance notation with a virtual dancer. This paper presents the setting and evaluation of key poses which form the foundation for ballet *steps* (combinatin of key poses) and how the application of Laban's Effort factors can be used for expressive interpolation between these poses.

1 Introduction

Like music, the choreographed movements that make up a dance performance can be written down, and the best known systems for doing so are Labanotation (Brown and Parker, 1984; Laban, 1966), Eshkol-Wachman (Eshkol and Wachmann, 1958) and Benesh notation (Brown and Parker, 1984; Benesh and Benesh, 1983). Choreography is primarily written down for archival purposes and to promote its dissemination to a wider audience. Unlike music, dance notation is not widely understood by dancers. There are few professional performers who can read written choreography let alone visualise the movements involved, and this represents a considerable barrier to the utility of choreography in its written form (see Figure 1).

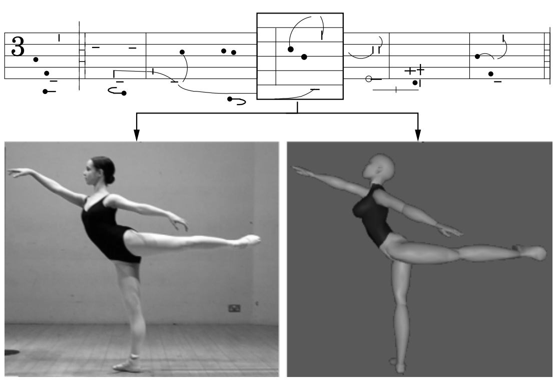


Figure 1: Example of a pose annotating using Benesh notation of an *arabesque* posed by a real dancer and virtual ballet dancer

Both the Labanotation and the Benesh notation give a rich vocabulary for describing human movement. They model structural and positional aspects of the performer at specific times and provide information on the timing and speed of movement, as well as qualitative aspects (i.e. how one moves). Benesh Movement Notation was designed by Rudolf and Joan Benesh in 1947 to represent classical ballet with its inferred rules such as turnout, rounded arms and straight legs. From the notation it is possible to reconstruct and visualise each pose and the movement required between the key poses.

Reconstructing dance using notation provides the foundation or blue print to the dance movement, the quantitive aspects. However, human activity is dynamically and rhythmically charged and structured, and people are recognised by the dynamic and rhythmic make-up which personalises their style of moving (Davies, 2003), the qualitative aspects. Our research is combining the two, and developing a virtual ballet dancer (VBD) where both aspects are required. The remainder of this paper starts by providing a brief background to the Benesh notation, the rules of classical ballet and Laban's dimensions of expressive movement. The machine-readable format used to input the Benesh notation is described followed by a detailed description and evaluation of the rules of ballet that were encoded into the VBD to allow it to adapt to the notated poses. The paper concludes by describing the methods that will be used to bring the VBD to life, animating its movement according to different motive themes in ballet.

2 Background

2.1 Benesh Movement Notation

In computer graphics, a skeleton-based approach is generally considered to be the most flexible way to animate characters (Badler et al., 1999; Herda et al., 2000). Benesh notation provides information, directly or inferred, that can be mapped to an articulated skeletal structure to specify the positions of the bones or the angle of each joint of a dancer. The symbolic representation of dance notation is similar to music and with an underlying mathematical content that also lends itself well to machine representation.

Written from left to right on a five-line stave, the stave lines map to the height of a person's feet, knees, waist, shoulders and top of the head. To record a pose, the Benesh notation notes the exact locations occupied by the four extremities (the hands and feet). In addition, the position of a bend, such as the knee or elbow, may also be defined. Given these points and the body and head positions, it is possible to reconstruct and visualise the whole pose (see Figure 2).

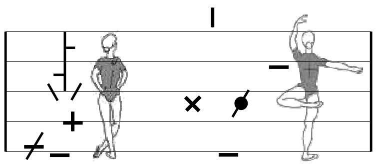


Figure 2: Examples of the Benesh notation showing signs to pose a dancer including orientation of the head and body, contact to the body (hand on hips), crossed positions of the extremities and different feet positions when in contact with the floor. The human figures show the actual poses that were defined.

Benesh also included floor patterns: direction, location and travel for the dancer or group of dancers written below the stave. Further details on travelling, direction, location can be found at page 87 in *Dance Notation for Beginners* (Brown and Parker, 1984) and page 70 in *Reading Dance* (Benesh and Benesh, 1983). Rhythm and phrasing are shown above the stave and include pulse beats, tempo and common dance rhythms. The pulse can be split into half, quarter and third beats and there are three methods for specifying the tempo: (1) set instructions, such as: Fast, Moderate, etc. (2) specifying the number of beats per minute by giving the pulse beat a metronomic speed; and (3) instructions as shown in music scores using Latin terminology, for example *Presto*, *Allegretto*, and *Adagio*.

For this paper, we are only concerned with the *in*-stave signs which provide the direction and orientation of the limbs, head, body and head either directly or by inferred ballet rules.

2.2 Ballet Rules

The basic rules of ballet were defined by Jean-Georges Noverre (1727-1810), the author of *"Lettres sur la Danse et sur les Ballets"* (Letters on Dance and Ballet) (Noverre, 1760), and Carlo Blasis (1797-1878), the author of *"The Code of Terpsichore"* (Blasis, 1830). The material in these books is virtually indistinguishable from ballet as it is taught to-day and specify many ballet rules. As ballet grows and choreographers define new positions and in the process create more exception to the rules. However, the basic rules remain unchanged and these rules will be used for the development of the current VBD system.

The ballet rules for the arms include rounded arms (with the exception of the *arabesque*) and arm orientation. The stance of the dancer is kept erect unless specified with the neck straight over the spine. The position of the legs always assumes a degree of turnout from the hip joint unless the notation specifies otherwise by defining the knee and feet positions.

This paper will be continually making reference to the following arm and leg ballet positions and the ballet rules required to pose them as described by the Cecchetti method. There are five principal positions of the arms:

1st Position. The hands are held at the side with the finger-tips near to the outside of the thigh.

2nd Position. The arms are extended to the side sloping downward and the position of the arms must not pass beyond the line of the shoulder.

3rd Position. One arm is placed in the fifth position, and the other placed at a slight distance from the side.

4th Position. One arm is placed in the second position and the other is in the fifth position, *en bas* (low), *en avant* (forwards) or *en haut* (high).

5th Position. Has both arms placed at shoulder width in front of the body. There are three derivatives of the fifth position: *en bas* (low), *en avant* (forwards), and *en haut* (high).

These five principal positions are posed with rounded arms, so that the point of the elbow is imperceptible. When the arms are to the side, the finger-tips of the hand or hands should be just within the range of vision.

For this research we will also consider the three principal positions for the arabesque line of the arms:

First Arabesque. The front arm is raised in line and above the shoulder line and the second arm is below and level or slightly behind the shoulder.

Second Arabesque. The front arm is in front and just above the shoulder line and the back arm is below and behind the shoulder line continuing the line of the front arm.

Third Arabesque. Both arms are in line with the shoulder and in front of the shoulder with one arm higher than the other.

This paper will also refer to five principal positions of the feet:

First position. Standing with heels together and toes turned out to the side.

Second position. Keeping the turnout established in First position, the heels are aligned under the shoulders.

Third position. Cross one foot to the middle of the other with hips centred equally over the feet and not twisted.

Fourth position. The feet are separated forward and back from either fifth or first position approximately one foot length with the weight evenly distributed between the feet.

Fifth position. The front heel crosses to the big toe joint of the back foot with hips centered over the feet and the weight equally distributed.

2.3 Expressive Movement

Analysis of expressivity in movement, especially dance movement, is not a simple task and there have been many approaches. Most of these use motion capture and then analyse the motion for patterns (Brand and Hertzmann, 2000; Price et al., 2000) or expressive cues (Camurri and Trocca, 2000). The accuracy of professional ballet dancer to position-match (Ramsay and Riddoch, 2001) and the constrained movement of ballet allowed Campbell and Bobick (1995) to use phased space constraints to recognise the different movements used in ballet.However, our research is interested in understanding the expressive layer placed over movement defined by ballet rules.

Laban's Effort and Shape theory (Dell, 1977) characterises the way in which people move. We are concerned with three particular factors: space, weight, and time. In EMOTE, Chi et al. (2000) gives excellent descriptions:

Weight: is the sense of impact of the movement and exertion required ranging from *light* (buoyant and delicate) to *heavy* (powerful with impact e.g. pushing or punching).

Time: describes the qualities of sustainment and quickness of movement as opposed to speed measured by the clock or tempo marked by a metronome. Time ranges from *sustained* (lingering and indulging in time) to *sudden* (agitated, jerky movements).

Space: is spatial focus and attention to surroundings, overlapping shifts in the body among a number of foci ranging from *indirect* (multi-focused) to *direct* (pinpointed and single focused).

Laban provides a fourth parameter called Flow. However, for our research this is superseded by the bounding imposed by the strict rules of classical ballet.

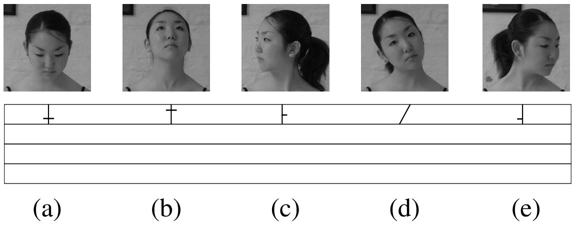
Experimental investigation of the fidelity required for showed that participants could correctly distinguish between different pairs of emotions in almost 80% of trials, even when the resolution, size, and display aspects of fidelity were reduced (Neagle et al., 2003). Participants performance remained largely unchanged when the video framerate of the experiments stimuli was reduced to as low as 5Hz. The results highlighted the time factor with other visual clues such as Laban's space and weight dimensions that participants used to make their judgements.

3 Inputting Key Poses

Virtual dance has developed over the last few years with three main approaches: (1) motion capture (Moeslund and Granum, 2001; Camurri and Coglio, 1998), (2) scripting (Badler et al., 1999), and (3) animations driven from machine-readable versions of dance notations (Badler, 1989; Neagle and Ng, 2003). Motion capture has mainly been used with contemporary dance with some development toward classical ballet including Stevens et al. (2002) and Camurri et al. (2000). Several programmes exist to create, store, and modify dance notations and include Benesh Notation Editor; MacBenesh; Calaban; LabanPad PDA (currently: Apple Newton); LabanWriter; and LED. There are limited visualisation tools and the best known research was LINTER (Herbison-Evans and Hall, 1989). However, while motion capture can provide many nuances in the movement, control of the animation is very limited and it is also labour intensive and costly. Movement of the VBD described in this paper are driven by a machine-readable version of the Benesh notation. The format ASCII text (Neagle et al., 2002) is parsed using a bespoke tokeniser. Examples of the format are shown below, and it is described more fully in Neagle et al. (2002).

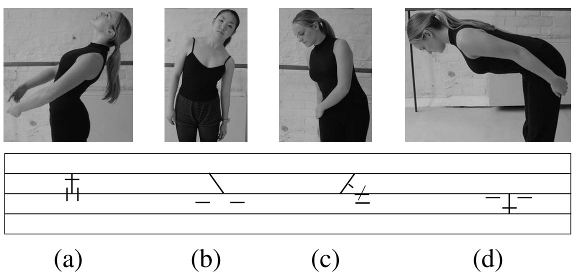
The orientation states for the head, body and pelvis are any combination of *tilt*, *turn*, *bend* (see Figure 3 and 4), and orientations represent rotations around the three cardinal axes. Benesh notation specifies these states using the top three spaces in the five-line stave. We see Benesh notation, using single signs to represent combinations of orientation. Examples of head orientation together with the associated machine-readable ASCII text are shown in Figure 3. Example of body and pelvis orientation are shown in Figure 4

To record a position or pose, the Benesh notation also notes the exact locations occupied by the four extremities, the hand and feet, in relation to the body of the dancer on the coronal plane. The position of extremity signs within the stave for each key pose denotes the position of the dancers hands and feet in relations to their anthropometrics. Benesh notation provides the height and width of the extremities' position in relation to a dancer standing upright. There are five defined height positions represented by the five lines of the Benesh notation stave: the floor (height is zero); knee height; waist height; shoulder height; and the head height. Width is specified proportionally to the horizontal reach of the limb along the




```
frame 1{head(bend,forward)}                  #(a)
frame 1{head(bend,back)}                     #(b)
frame 1{head(turn,right)}                    #(c)
frame 1{head(tilt,right)}                    #(d)
frame 1{head(bend,forward)(turn,right)}      #(e)
```

Figure 3: Examples of the Benesh notation and machine-readable text format for head orientation. (a) and (b) are bends, (c) is a turn, (d) is a tilt, and (e) is a combination of a turn and a bend. NB. the notation is represent from behind the body and therefore the signs are notated in the opposite direction of the photos for the rotation and tilts.




```
frame 1{                              #(a)
  body(bend,back)
  lefthand(0.1,3.0)front
  righthand(0.1,3.0)front
}
frame 1{                              #(b)
  body(tilt,left)
  lefthand(0.1,2.75)level
  righthand(0.1,2.75)level
}
frame 1{                              #(c)
   body(tilt,right)(turn,right)
  lefthand(-0.1,3.0)contact
  righthand(0.1,2.75)level
}
frame 1{                              #(d)
  pelvis(bend,forward)
  lefthand(0.1,2.75)level
  righthand(0.1,2.75)level
}
```

Figure 4: Orientation of the Benesh notation body and pelvis signs. (a) is a bend of the body above the waist, (b) a tilt, and (c) a turn and tilt. Images (d) shows a bend of the body below the waist (pelvis).

cardinal plane. For example, a width specification for the hand of half way from the centre of the body to the maximum reach would position the hand approximately where the elbow is.

The depth of an extremity is inferred from its position mapped onto the coronal plane plane and the orientation of the relevant limb(s). Different sets of signs are used to add depth information to the two-dimensional information provided by the position of a sign on the stave. These sets of signs are: front (| , ┼ , ⫽), level (− , + , ≠) or behind (• , × , ⊁) the body. The distance in front or behind the body is not specified as only one place is possible due to the fixed limb length. It is also not required to specify how bent the limb is, as this is governed by the position of the extremity and the position of the bent joint. The legs are positioned in a similar manner to the arms with the exception that the floor contact is specified. Unless a bent knee position is notated to define the orientation of the legs, the default turnout rule is applied (a rotation in the hip socket for the patella bone to face the side).

4 Defining Key Poses of a VBD

To teach dancers the movements prescribed by a particular piece of ballet notation, choreographers combine the information provided by the notation with their knowledge of the rules of ballet. The notation defines the positions of the key elements of a dancer's body, who then adopts a pose consistent with those positions and the standard rules of ballet. To define key poses for a VBD, the rules of ballet need to be expressed as a set of mathematical equations which were merged with the machine-readable Benesh notation data.

The VBD used in this research was the Cal3D software (Heidelberger, 2001) and has the degrees of freedoms (DOF) shown in Figure 5. The following sections explain how the information contained in Benesh notation can be combined with equations that capture the rules of ballet, to define the DOFs of a VBD's body. The centre of body nodes (pelvis, waist and neck), the shoulder nodes and the hips have three DOFs. The elbow nodes have two to: (1) bend the elbow; and (2) rotate the forearm to orientate the palm of the hand. The wrist nodes have one DOF to raise and lower the hands when setting rounded arms.

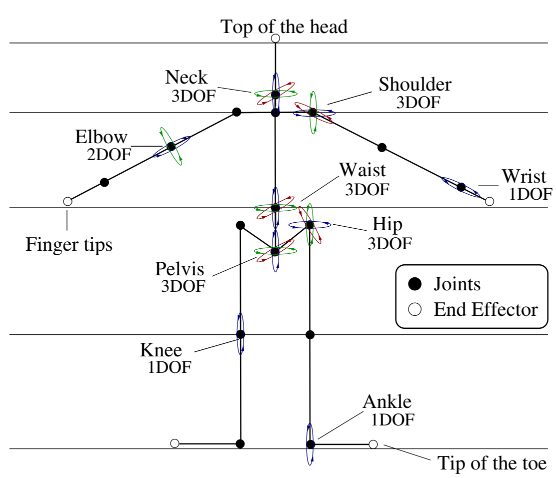


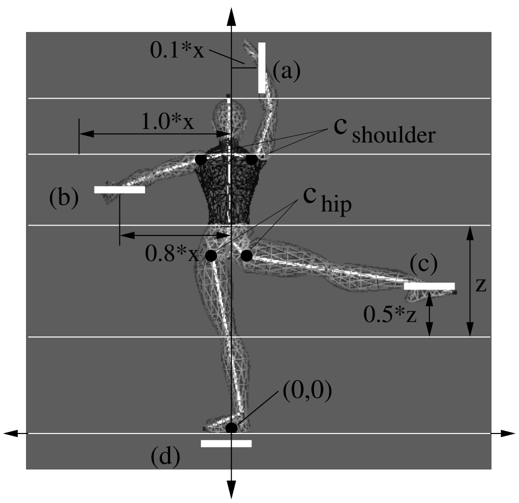
Figure 5: The skeletal structure of the VBD, showing the end effectors and the DOFs at each joint.

The knee nodes have one DOF to flex and straighten the leg and the ankle nodes have one DOF to flex and point the foot.

4.1 Setting Joint Positions

Before calculating positions the VBD is loaded in a default standing pose. The height (z) values of the knee, waist, shoulder and head are calculated from the VBD's bone structure and set as the stave heights. For example, the waist height z_{waist} is stored as the third stave line height. The maximum width for positioning the hands and legs are taken form the sum of the bone lengths that make up the limbs for those extremities.

Positions are explicitly notated in terms of height (z), width (x), and depth (y). Figure 6 demonstrates the position of the extremities. The file format representation




```
frame 1{
   righthand(0.1,5.5)front #(a)
   lefthand(0.8,3.5)level  #(b)
   rightfoot(0.9,2.5)level #(c)
   leftfoot(0.1,0.75)level #(d)
}
```

Figure 6: An example of Benesh notation, the file format representation and the VBD posed inputed from the file.

in this example specifies the position of each extremity as a tuple and a word, e.g. level, that defines the depth. The width parameter, though redundant and unused for calculating the position for extremities which are level, it is however required in the calculation of the ballet rules. The right foot, in Figure 6, is notated half way between the second and third stave line. The application therefore obtains the height of the second stave (knee height of the VBD) and the height of the third stave line (waist height) and calculates the height of the foot as:

$$z_{position} = z_{stave2} + p(z_{stave3} - z_{stave2}) \qquad (1)$$

where p is the proportion value (0.5).

Given the value of the height, the end effector can be calculated. When the appendage is in the body plane, this is a simple 2D problem using Pythagoras. Given the length of the limb (l), the height ($z_{position}$), and the rotation point of the extremity i.e. the hip or shoulder joint in absolute space ($c_{(x,y,z)}$, $c_{shoulder}$ or c_{hip} in Figure 6) the width position is calculated as:

$$x_{position} = \sqrt{l^2 - (z_{position} - \underline{c}_z)^2} + \underline{c}_x \qquad (2)$$

The position of the extremity (in this case the right ankle joint) is set as $(x_{position}, c_{hip\ y}, z_{position})$.

The above approach is easily extended into three-dimensional space for positioning the extremities in front or behind the body plane. The width (x) is calculated proportional to the length of the straight limb. For example if the arm span of the VBD is 1 metre, a notation width parameter 0.1 defines the hand to be 0.1m from the shoulder (see Figure 6, the raised arm above the head is notated with width 0.1 and height half way between the top of the head and a raised stretched arm (5.5)). Once the $x_{position}$ and the $z_{position}$ has been calculated (see above), the depth ($y_{position}$) is calculated using Pythagoras:

$$y = \pm\sqrt{l^2 - (x^2_{position} - \underline{c}_x) - (z^2 - \underline{c}_z)} + \underline{c}_y \qquad (3)$$

where $y > c_y$ is in front of the coronal plane and $y < c_y$ is behind the coronal plane.

4.2 Rounded Arms and Elbow Positions

Like the Benesh notation, the VBD will assume the arms are rounded unless elbow joints are specified or the position is identified as one of the three *arabesque* positions where the elbow and wrist rotation is set to $0°$. The rounded arm is produced by a slight bend of the elbow and wrist, examples are shown in Figure 7. The amount of curvature varies depending on the ballet method and teachers preferences. The prototype therefore is designed for the user to specify the amount curvature. Screenshots in this paper with rounded arms were set at 154° based on the first authors professional opinion. The amount of rotation affects only the depth position of the wrist and the height and width values are obtained as described in §4.1 with the length l in Equations 1–3 calculated using trigonometry given the fixed length of the upper and lower limbs and the specified rounded angle. Once the wrist position is obtained, the vector u is the vector from the position of the shoulder joint to the position of the wrist joint, see Figure 8.

The position of the elbow in classical ballet is on a plane defined by the vector from the shoulder to the wrist u and a vector parallel to the floor w. The ballet rule states the elbow should not be dropped down or raised too high but continue the line of the slope to the hands. The position of the elbow joint is calculated using sphere intersection to obtain a point (p_{inner}) on the vector (u) and Pythagoras to translate the p_{inner} along a vector (v)

(a) *secondé* position

(b) *pirouette* position of the arms

Figure 7: (a) *a la secondé* demonstrates rounded arms with the hand brought forward within the dancers line of sight. (b) *pirouette* position of the arms demonstrating the rounded arms the elbow position on a plane continuing the line from the shoulder to the wrist.

which is on the plane and parallel to the floor from p_{inner} (see Figure 8)

$$p_{inner} = p_{shoulder} + \left(\frac{|u|^2 - l_{upper}^2 + l_{lower}^2}{2|u|^2} \right) u \quad (4)$$

The vectors are normalised to unit vectors and the cross product of w and u provides n and taking the cross product of n and u provides the vector v. The elbow position is calculated as:

$$\begin{aligned} d &= \sqrt{l_{upper}^2 - (p_{shoulder} - p_{inner})^2} \\ p_{elbow} &= p_{inner} + dv \end{aligned} \quad (5)$$

where d is a scalar and the magnitude required to position the elbow from p_{inner} in the direction of vector v.

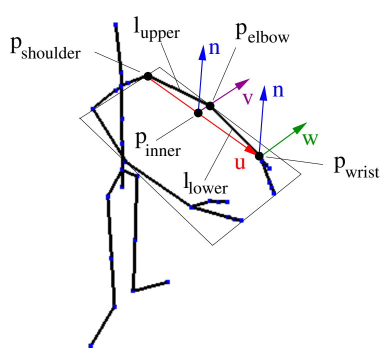


Figure 8: Vectors, points and limb lengths used to calculate the position of the elbow on a plane defined by the vector u (shoulder to wrist) and w (parallel to the floor).

4.3 Specified Elbow Position and Rotation

Benesh notation can override the ballet rules by specifying the elbow and wrist positions individually. The elbow position is determined as described earlier (Equations 1–3), given the width and the height of the elbow, the depth is calculated in relation to the shoulder position. The notation also provides the width and height of the wrist position and the depth direction. Using the elbow as the rotation point the wrist positions coordinates are calculated and the amount of elbow rotation is calculated from the three coordinates, (u, v, and w) as:

$$\theta = \cos^{-1} \left(\frac{(u - v) \cdot (w - v)}{|u - v||w - v|} \right) \quad (6)$$

where u is the shoulder coordinates; v, the elbow coordinates; and w, the wrist coordinates.

4.4 Arm Orientation

For poses with bent arms, the z-axis of the shoulder and elbow is orientated perpendicular to the plane that contains the lower and upper arm. Vectors running along the length of the upper and lower arm are used to calculate the orientation of the shoulder. Arabesque poses have straight arms, and so require a slightly modified procedure (see Figure 9). Once calculated, the vectors are set in a rotation matrix which for the model used with the Cal3D libraries in the VBD is:

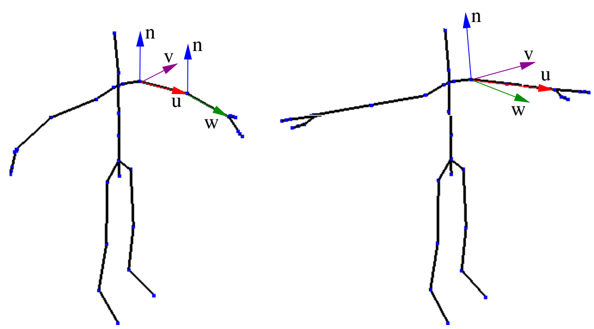


Figure 9: The left diagram demonstrates the orientation of the shoulder determined using the upper and lower arm vector. The cross product of w and u provides n where u is the x-axis and n is the z-axis. The y-axis v is obtained from the cross product of n and u. The right diagram demonstrates *arabesque* with straight arms where a vector (w) parallel to the floor and not parallel with u is substituted for the lower arm vector. All of the vectors are unit vector.

$$r_{matrix} = \begin{pmatrix} u_x & u_y & u_z \\ v_x & v_y & v_z \\ n_x & n_y & n_z \end{pmatrix}$$

The matrix is converted to a quaternion to set the rotation.

The rotation of the wrist has been simplified and for rounded arms uses the same rotation angle calculated for the rounded elbow and rotated around its one DOF. The orientation for rounded arms to orientate the palms to face the correct direction is calculated in the elbow rotation rotated at 90° around th axis running along the lower arm bone. For the arabesque pose, the wrist rotation and elbow rotation are set as the identity quaternion.

4.5 Head, Body and Pelvis Rotations

The Benesh notation defines three rotations around each axis: *bend*, a *x-axis* rotation, *tilt* a *y-axis* rotation, and *turn*, a *z-axis* rotation where for the head bone of the VBD the x-axis is left to right; y-axis is front to back; and the z-axis is bottom to top. For this report we will use this coordinate system and the Euler angles are $(r_{bend},\ r_{tilt},\ r_{turn})$. The VBD currently calculates the rotations to the limit for that particular DOF. Each joint DOF limit have been selected based on the authors judgement within the range specified in Grosso et al. (1987) based upon the NASA Man–System Integration Standard Manual in *Occupational Biomechanics* by D. B. Chaffin.

The rotation limits are used specifically for setting key poses and the amount a rotation is variable depending on the expressive movement parameters to be devised for the next stage of research. The rotations of the centre joints as discussed in §3 is simple achieved by using quaternion multiplication where the quaternion is calculated for each Euler angle. The order of multiplication is important and rotations of 0° are set as identity quaternions.

$$q_{rotation} = q_{turn} \times q_{tilt} \times q_{bend} \tag{7}$$

4.6 Rules for the Lower Extremities

Positioning the legs follows the same rules as the arms replacing the rules for calculating rounded and straight arms with turnout and floor position. Turnout of the legs in the hip socket is one of the fundamental rules for classical ballet. The perfect dancer is aiming to have 90° rotation. However because few dancers have perfect turnout. The applications allows for the user to specify the turnout for the VBD up to a maximum value of 90°. The rotation is around the axis of the bone

Benesh notation specifies the position of the feet on the floor. Using the width parameter in the depth direction it is possible to determine if the feet are posed in one of the five basic feet positions, is a supporting foot or a position not defined by the ballet rules. Ballet rules in the application set the position of the feet for the basic positions and if a supporting leg is specified (see Figure 6, left leg). The width position of the feet and the depth provided by the Benesh notation and using Equation 3, all other feet positions can be calculated as a vertical distance from the hip joint. Unless the foot position is in a line from the hip to the floor, and the calculation is taken from the hip joint, the height of the foot position will not be connected to the floor. A vertical translation of the parent node is calculated to reset the foot to the floor.

5 Evaluation of Key Poses

5.1 General Methodology

The evaluation compared key poses of the VBD, as determined by combining machine-readable Benesh notation with the rules of ballet programmed into the VBD application, with corresponding poses described in *The Manual* (Beaumont and Idzikowski, 1977). The images from The Manual were used by permission of the Imperial Society of Teachers of Dance (ISTD). Images of each pose taken from the text book were set adjacent to the image screen grabbed from the VBD and only differences highlighted for comparison. The poses were selected to demonstrate the use of the different rules used by the VBD.

5.2 General Pose Descrepancies

The VBD uses the human model provided with the Cal3D libraries. Although this is an excellent starting point there are some discrepancies that need to be addressed. The most obvious is the shape and proportions of the Cal3D model in respect to the real-world ballet dancers used in this research. These includes, most noticeably, the breast size and the shape of the legs. Figure 11 shows the VBD has noticeably curved thigh muscles and a 's' shape to the leg, whereas ballet defines this shape as a straight leg. The three major classical ballet factors which are less obvious to non-professionals are the orientation of the head; the shape of the hands; and there being no toe joint.

Head Orientation

Blasis states *"Take especial care to acquire perpendicularity and an exact equilibrium"* (Blasis, 1830). Figure 10(a) shows the spine in the head is sloped slightly backward and is not perpendicular to the ground and the mesh is both forward and down . For a classical ballet stance as described by Blasis, the head should be perpendicular to the ground and the centre of the mesh aligned so there is a sense of equilibrium. Currently the VBD appears top heavy and forward.

The Hands, Legs and Feet

The Manual describes the shape of the hands for classical ballet and provides variations in the positions of the fingers for different positions. These variations are minor and therefore for the VBD, a single classical shape would would suffice. However the Cal3D model currently used has an open hand which is incorrect for a classical dancer, as shown in Figure 10(b). This incorrect hand pose has been highlighted in both evaluated poses. See Figure 12, difference (c) and Figure 13, difference (c).

The pointed foot currently is an issue when the foot is lifted off the ground or defined touching the ground on full point (*sur la pointe*). This like the hands is a theme

(a) (b) (c)

Figure 10: (a) The VBD with skeleton and wire mesh surface display, with the head positioned in the default anatomical position. (b) A classical hand position as defined in *The Manual*, Plate IV Fig. 17 (left) and the open palmed VBD hand (right). (c) The pointed foot extended as much as possible with the instep forced well outwards and the *pointe* forced downwards taken from Plate III, Fig 11 (left) and the VBD without a toe joint showning the rigid foot with the *pointe* created with only the ankle rotation.

that will run through every pose when a pointed foot is required. To have every possible foot pose requires the toe joint to be added to the skeleton which is currently not part of the Cal3D model (see Figure 10(c)). Because the shape of the foot remains unchanged from flat to pointed, when a pointed foot is required the shape is noticeably rotated only at the ankle joint. See Figure 13, difference (e) on all images. The basic feet positions have minor errors as shown in Figure 11 for the *first* to *fourth* position and Figure 12 for the *fifth* position.

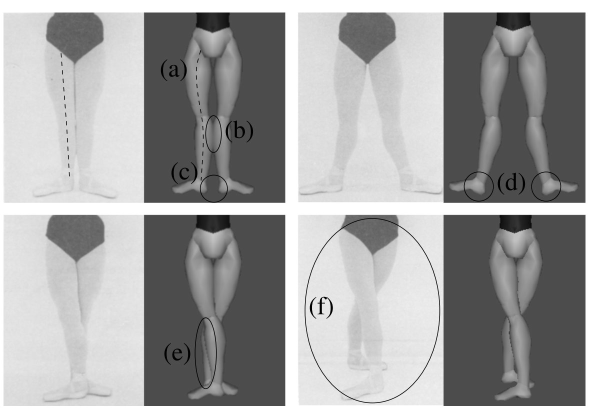


Figure 11: Positions of the feet from Plate I of The Manual (Beaumont and Idzikowski, 1977) and VBD in the same pose . The poses are from left to right: *first, second, third,* and *fourth croisée* position. Highlighted differences: (a) straight legs on the VBD appears 's' shaped (b) no mesh deformation resulting in intersecting mesh; (c) distance between heels due to leg shape of the VBD model; (d) ankle rotation is currently incorrect; (e) back leg can be viewed due to leg shape of the model; and (f) the real-world dancer has been photographed with the hip orientation off centre creating a slight twist in the shape.

Both the reshaping of the hands and skeletal change in the feet are required to add a greater level of fidelity to the classical pose. However, for this research, the fidelity of the dancer is high enough to demonstrate classical ballet poses that professionals and non-professional can recognise and/or compare to real-world examples.

5.3 Standard Poses in Fifth Position

The poses that were evaluated combined of poses position the feet in *fifth* position (the corner stone of ballet) and a combination of different arm and body positions based on the five basic ballet positions and their derivatives that were outlined in §2.2. The example in Figure 12 is slightly lower than normal as the Manual is also describing the pose from the *First* Exercise on the *Port de Bras*, No. 2.

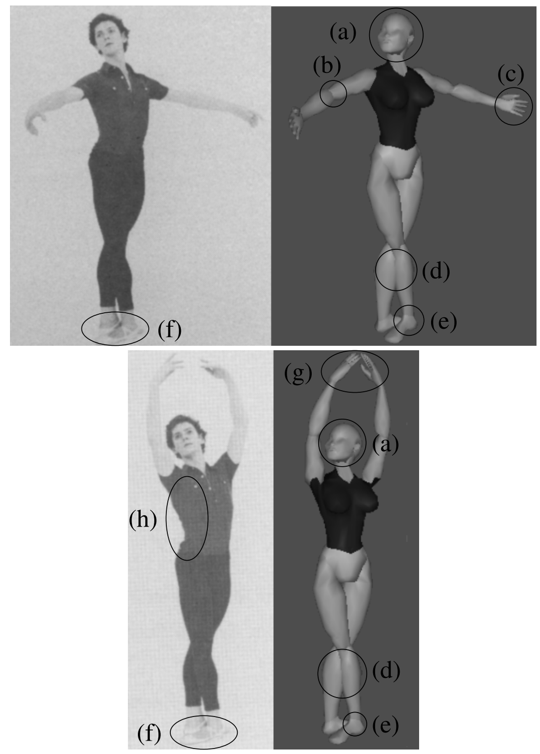


Figure 12: Pose from The Manual (Beaumont and Idzikowski, 1977) and VBD in the same pose . The poses are: *fifth position* with arms *a la seconde* (left) and *fifth position* with arms *fifth en haut* (right). Highlighted differences: (a) head turn and incline combination; (b) amount of elbow bend for rounded arms and orientation; (c) classical hand position; (d) collision detection and mesh deformation; (e) ankle rotation (toe position is slightly below floor level); (f) twisting of the joints to squeeze a better fifth position (common in posed photographs); and (g) width of hand placement.

Comparing the real-world pose with the VBD in Figure 12, the following differences were identified:

(a) Current coding of the combination head rotations are currently incorrect. The assigned values for the rotations are set as a value not taking into consideration the arm positions and the authors at the time of coding misunderstood the different variation in the Benesh notation and the affect the combinations have on the orientation of the head. The orientation therefore is currently only a close approximation.

(b) The current elbow bend and orientation specified by the authors professional opinion varies from the manual. The value for the bend is currently set from measurements taken from the authors own pose of the rounded arm as discussed earlier. The orientation is set to 90° around the bone axis. From Figure 12 we observe the VBD's lower arm orientation is greater than the real-world dancer. However the amount of rotation to orientate the lower arm varies between dance methods and the dancers themselves and other poses of the same arm position taken from The Manual demonstrate a greater rotation.

(c) The pose of the hands has been discussed earlier (see §5.2)

(d) The libraries used to create the VBD currently have no collision detection and therefore deformations of the mesh are only related to rotations around the joint. The real-world dancer's calf muscles have been compressed as we see that the legs are still straight (i.e. no bend at the knee joint). When the VBD is posed in the same position, the meshes intersect. Correcting this is beyond the scope of this research.

(e) The VBD is currently not being placed in a virtual environment and therefore no compensation of the ankle rotation has been coded to check if parts of the anatomy intersect the floor plane.

(f) The real-world dancer is using the pressure of the floor to have what is termed a tighter fifth position (toes are pressed against the heel of the other foot). This is noticeable on the real-world dancer as the direction of the hips (to the corner) do no match the direction of the feet (direction closer to facing the front). Current teaching tries to avoid this, however, when asked to pose for a still photo, most professional dancers will use floor pressure to rotate the ankle and knee joints incorrectly to create a tighter position. The Manual demonstrates the *fifth* position of the feet which the VBD maps accurately with respect to the defined turnout.

(g) The hands of the VBD are too close together. Increasing the separation will allow the elbow bend rotation to increase to visually make a more rounded shape.

(h) The hint of the back bend shown by the real world dancer is a level of fidelity that the VBD does not achieve. The slight bend is a part of the Cecchetti style and the image is a pose from the *Third* Exercise of *Port de Bras*. This variation in shape is hoped to be achieved from the movement algorithm discussed in the next chapter.

5.4 The *Arabesque* Poses

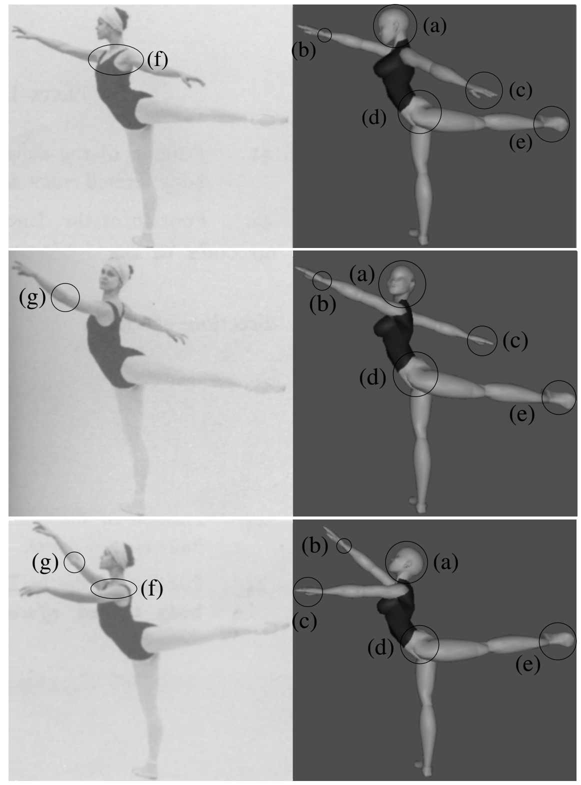


Figure 13: Poses from The Manual (Beaumont and Idzikowski, 1977) (left) and VBD in the same pose (right). The poses are: *first arabesque* from Plate VIII, Fig. 36 (top); *second arabesque*, Plate VIII, Fig. 37 (middle); and *third arabesque*, Plate VIII, Fig. 38 (bottom). Highlighted differences are: (a) head descrepencies; (b) break in the wrist joint; (c) classical hand position; (d) pelvis compensation for turnout; (e) classical foot shape; (f) rotation of the shoulders; and (g) slight break in the elbow to create a softer appearance (common with the female dancer).

The *arabeque* pose is one of the most used in classical ballet choreography and therefore has been selected as our second evaluated pose. As in the earlier section the visually noticeable differences have been highlighted:

(a) This is a recurring theme and was discussed in the previous evaluated pose. An extension to the problem can be seen in the bottom pose of Figure 13 where the head line (direction of the head) is slightly raised to look at the top hand. Whether a choreologist would define a head back position as seen in the VBD of the same pose or leave it undefined is at this stage unsure. If undefined, a new level of fidelity to the ballet rules would need to be added to compensate 'looking at the raised front hand'.

(b) Most classical dancers place a slight break in the wrist to create the illusion of a softer position. The amount of break varies from dancer to dancer and therefore the VBD was coded without. When compared with the real-world pose however, the VBD's arms appear very rigid and stiff would be corrected by a dance teacher.

(c) The pose of the hands has been discussed earlier, see §5.2.

(d) The rotation of the hips by the real-world dancer is used to provide the required turnout of the raised leg. Depending on the dancers body this can vary a great deal. Dancers spend years of training to minimise the amount of twist required. The VBD is therefore in a technically correct but unrealistic pose in the sense that most professional dancers will use some amount of hip rotation to create a better leg line.

(e) We see that the bottom half of the foot does not match the real-world pose. This is due to the toes of the VBD not having the functionality to be pointed. See §5.2 for the discussion on the pose of the feet.

(f) The real-world dancer has rotated the shoulder. Though, technically, students are trained to be in what is classified as a square position (both shoulders facing the direction and not a corner), many professionals rotate the shoulders to create a better arm line and to make it easier to raise the hips to create better turnout of the legs. Because of the different teaching methods and the technical description of an *arabesque* pose the VBD will keep its shoulders square.

(g) The real-world dancer in this pose, arguably, has too much bend in the elbow joint. It is of the authors professional opinion that the arabesque pose has straight or nearly straight (if creating a softer appearance) arms. The amount of bend is difficult to assign and varies between dancers and therefore the VBD currently sets the arabesque pose with straight arms.

6 Emotive Animation

Ballet dancing not only requires technique to perform the poses and movement, but expressiveness to create a performance and not a series of steps. Benesh notation provides movement arcs to define the path of the extremities between poses and general movement descriptors to orientate (direction of the body) and position (height of the *saute*/jump or *plié*/bend) the dancer. Using Laban's Effort parameters it is possible to define variations in the interpolation that are distinguishable to the audience. The Effort factor are ranged between the two extreme values associated with each effort to capture the many different expressive movement.

Time is not the speed of the movement between key poses but how the speed of movement varies. Given the two extreme parameters are sustained and sudden, an equivalent concept is in music where sustained is playing a long consistent note and sudden is an accented note with a quieter sound afterwards. A movement equivalent is shown in Figure 14. The attack segment of the movement will require and acceleration and deceleration period at the beginning and end of the attack period as motor motion does not have jumps in velocity.

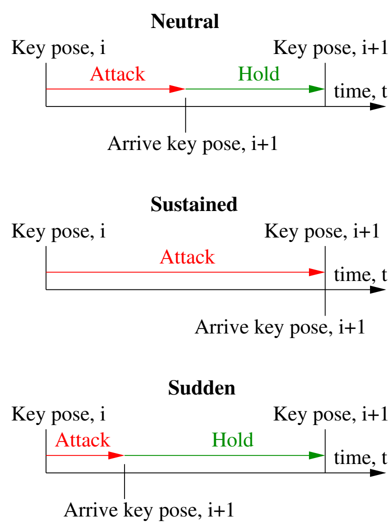


Figure 14: Variations on Laban's time factor for interpolation

Laban's space factor ranges between direct and indirect. For classical ballet a different application toward movement in space is required when looking at arms, legs and the spinal orientation. The main cue for expressive movement comes from the use of the arms in classical ballet. A direct path is not a straight line but the shortest path between key poses. Ballet movement is based on a circular geometry and Benesh notation infers that the shortest most direct path will be taken by the extremity unless specified otherwise (see Figure 15). By defining movement rules for space that deviates away from the inferred movement path within the bounds of the ballet rules, the VBD arm movement will utilise more space around the body and therefore more indirect movement. Currently, the VBD poses the centre joints (head, waist and pelvis) rotated at their respective maximum joint limits for each DOF. A direct specification rotates only around the axis specified by the notation and an indirect specification specifies rotations with a minor value to the other two axes. In classical ballet the legs not only achieve ballet poses but is fundamentally to supporting the dancer and must be considered when applying the expressive layer. The movement of the legs is therefore more bounded to

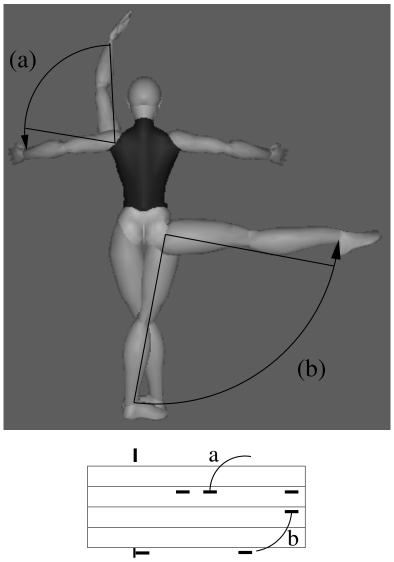


Figure 15: Example of the shortest path from a pose with feet in *fifth* position and arms in *fourth en haut* to standing *a la seconde*. Variation from the specified path leads towards indirect movement. Unspecified movement paths will always assume the shortest ballet movement path.

keep the dancer balanced and supported. Altering the position of the supporting legs as specified in the notation could create unbalanced poses and movement a real dancer is physically unable to achieve. For this research the space factor will only affect the raised leg movement and the path taken within the the strict bounds of the classical ballet rules. For example variations from the movement path can not bend the knee unless specified in the notation as this breaks the rules of classical ballet and limits the amount of spacial variation compared to the arms.

The final factor is the weight of the movement, described by Laban as ranging from heavy to light. The major cues for distinguishing differences in the weight are from the arms and legs. In classical ballet, the torso is strongly held and a strong abdomen is required for a dancer to have adequate technique to perform ballet steps. Variations of the weight effort would therefore be minimal for the spinal joints and we will focus on the extremities. Weighty dancing can be distinguished by the amount of *plié* used by the dancer. The greater the knee bend the more weighty (heavier) the feel. For the arms the approach is different. How the arm moves between key poses provides cues to the audience on the weight of the movement being performed. The most observable joint is the wrist rotation. For the wrists Blasis proposed that: *"There are two methods of moving the wrists, upwards and downwards. When the movement is to be made downwards, the wrist must be bent inwards, moving the hand demi-circularly, by which movement the hand returns to its first position; but care must be taken not to bend the wrist too violently, for it would then appear as if broken. With respect to the second movement, which is upwards, the wrist must be bent in a rounded position, allowing the hand to turn upwards, making a demi-tour or half-turn*" (Blasis, 1830). A light weight would have more flex in the wrist joint creating an illusion of a feather movement similar to the wrist action when painting with a brush. A heavy movement will have little rotation of the wrist giving a strong more solid and therefore more powerful feel to the movement.

The motivation of this project is to provide a system that will aide the realisation of a notated piece of dance into a live performance during rehearsals. A system that can simulate performed dance sequences as required by the choreographer or choreologist using the key poses as defined by the notation. The full development of a software animation system to represent and simulate dance would be beneficial to historians, choreographers and choreologists to: (a) evaluate ballet choreography with expressive styles, and (b) aide professionals to visualise the movement required for resurrecting ballet scores. Historically, dance provides a medium for open expression and conveying feelings revealing inner thought. The final system hopes, by synthesising expressive dance movement using VE technologies, to lead to better understanding of how animation provides visual cues to the virtual characters feelings while performing a very specific constrained rule based task.

Acknowledgements

A special thanks to Jon Singleton and Linda Pilkington from the I.S.T.D. for granting me permission to used images from *The Manual* for evaluation. Also, to Kate Simmons at Kate Simmons Dance Ltd. for allowing me to photograph their full-time professional dance students in ballet poses required for the VBD.

References

N. Badler. *A Computational Alternative to Effort Notation*, chapter 3, pages 23–44. National Dance Association, 1989.

N. Badler, C. Phillips, and B. Webber. *Simulating Humans: Computer Graphics, Animation and Control*. Oxford University Press, 1999.

C. Beaumont and S. Idzikowski. *A Manual of The Theory and Practice of Classical Theatrical Dancing*. Beaumont Publication, revised edition, 1977. Manual for the Cecchetti Method of Classical Ballet, Preface by Maestro Cav. Enrico Cecchetti.

R. Benesh and J. Benesh. *Reading Dance: The Birth of Choreology*. McGraw-Hill Book Company Ltd, first edition, 1983.

C. Blasis. *The Code of Terpsichore*. London, E. Bull, 1830. The Code of Terpsichore. The art of dancing, comprising its theory and practice, and a history of its rise and progress, from the earliest times by C. Blasis. Translated under the author's immediate inspection by R. Barton.

M. Brand and A. Hertzmann. Style machines. In Kurt Akeley, editor, *Siggraph 2000, Computer Graphics Proceedings*, pages 183–192. ACM Press / ACM SIGGRAPH / Addison Wesley Longman, 2000.

A. Kipling Brown and M. Parker. *Dance Notation for Beginners*. Dance Books Ltd, 1984.

L. W. Campbell and A. F. Bobick. Recognition of human body motion using phase space constraints. In *ICCV*, pages 624–630, 1995.

A. Camurri and A. Coglio. An architecture for emotional agents. *IEEE Multimedia Journal*, 5(4):24–33, December 1998.

A. Camurri, S. Hashimoto, M. Ricchetti, A. Ricci, K. Suzuki, R. Trocca, and G. Volpe. Eyesweb - toward gesture and affect recognition in dance/music interactive systems. *Computer Music Journal*, 24(1):57–69, 2000.

A. Camurri and R. Trocca. Analysis of expressivity in movement and dance. In *Colloquium on Musical Informatics Proceedings*, July 2000.

D. Chi, M. Costa, L. Zhao, and N. Badler. The EMOTE model for effort and shape. In Kurt Akeley, editor, *Siggraph 2000, Computer Graphics Proceedings*, pages 173–182. ACM Press / ACM SIGGRAPH / Addison Wesley Longman, 2000.

M. Davies. *Movement and Dance in Early Childhood*. Paul Chapman Publishing, second edition, 2003.

C. Dell. *A Primer for Movement Description*. Dance Notation Bureau, Inc, forth edition, 1977.

N. Eshkol and A. Wachmann. *Movement Notation*. Weidenfeld and Nicolson, first edition, 1958.

M. Grosso, R. Quach, E. Otani, J. Zhao, S. Wei, P. Ho, J. Lu, and N. Badler. Anthropometry for computer graphics human figures. Technical Report MS-CIS-87-71, University of Pennsylvania, 1987.

B. Heidelberger. B/e/o/s/i/l: Cal3d, a free 3d animation library. `http://cal3d.sourceforge.net/`, 2001. Last accessed February 2004.

D. Herbison-Evans and N. Hall. The computer interpretation of classical ballet terminology. *Technical Report*, (TR364), 1989.

L. Herda, P. Fua, R. Plänkers, D., R. Boulic, and D. Thalmann. Skeleton-based motion capture for robust reconstruction of human motion. In *Computer Animation*, Philadelphia, PA, May 2000.

R. Laban. *Choreutics*. MacDonald and Evans Ltd, second edition, 1966.

T. B. Moeslund and E. Granum. A survey of computer vision-based human motion capture. *Computer Vision and Image Understanding: CVIU*, 81(3):231–268, 2001.

R. J. Neagle, Ng K., and R. A. Ruddle. Notation and 3D Animation of Dance Movement. In *Proceedings of the International Computer Music Conference (ICMC2002)*, pages 459–462, September 2002.

R. J. Neagle and K. Ng. Machine-representation and Visualisation of a Dance Notation. In *Proceedings of the Electronics Imaging and the Visual Arts (EVA2003)*, pages 22.1–22.8, July 2003.

R. J. Neagle, K. Ng, and R. A. Ruddle. Studying the fidelity requirements for a virtual ballet dancer. In *Proceeding of Vision, Video and Graphics Conference (VVG2003)*, pages 181–188, July 2003.

J. G. Noverre. *Lettres sur la danse et sur les ballets*. Editions Ramsay, 1760. Jean-Georges Noverre, Letters of Dancing and Ballet, Translated from revised and enlarged edition (St Petersburg 1803) by Cyril W. Beaumont, London 1930.

R. Price, C. Douther, and M. A. Jack. An investigation of the effectiveness of choreography for the portrayal of mood in virtual environments. In *Proceedings of the fourth international conference on Autonomous agents*, pages 54–55. ACM Press, 2000. ISBN 1-58113-230-1.

J.R.E. Ramsay and M.J. Riddoch. Position-matching in the upper limb: professional ballet dancers perform with outstanding accuracy. *Clinical Rehabilitation*, 15 (3):324–331, June 2001.

C. Stevens, S. Mallock, R. Haszard-Morris, and S. McKechnie. Shaped time: A dynamical systems analysis of contemporary dance. In *Proceedings of the 7th International Conference on Music Perception and Cognition, Sydney*, pages 161–164, 2002.