Generation of Whole-Body Expressive Movement Based on Somatical Theories

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Abstract

An automatic choreography method to generate life-like body movements is proposed. This method is based on *somatics* theories that are conventionally used to evaluate human's psychological and developmental states by analyzing the body movement. The idea of this paper is to use the theories in the inverse way: to facilitate generation of artificial body movements that are plausible regarding evolutionary, developmental and emotional states of robots or other non-living movers. This paper reviews somatic theories and describes a strategy for implementations of automatic body movement generation. In addition, a psychological experiment is reported to verify expression ability on body movement rhythm. This method facilitates to choreographing body movement of humanoids, animal-shaped robots, and computer graphics characters in video games.

Keywords: Automatic choreography, Generation of life-like movement, Somatics, Emotional expression, Nonverbal communication.

1 Introduction

1.1 General problems of artificial body expression

Nowadays we often see artificial bodies such as humanoids, animal-shaped robots and computer graphics characters of video games that move their body like real humans and animals. In this paper, the author calls them *somatic expressive artifacts.*

One of major problem on controlling somatic expressive artifacts is difficulty on producing life-likeness of their behavior. Life-likeness can be detailed as the following 6 sub-impressions.

1) The first sub-impression is plausibility on body motion. There exist common rules and limitations among spatial and temporal patterns of real-life body motions, so that human minds have template or schema of life-like body motion. Artificial body motion generated without consideration therefore might be awkward when it disagrees with the schema.

In order to solve this problem, conventional video game systems that show artificial body movement, employed motion-capture method. The motions of artificial characters were choreographed with identical copies and slightly deformed copies of real-life motion that are enough plausible for humans. However motion-capture method has disadvantages on interactivity and adjustability, since captured data are difficult to segment and edit.

2) The second sub-impression is plausibility on fluctuation of motion patterns. Real-life body motions are always more or less different. Artificially generated body motion, in contrast, might be identical when it is repeated automatically.

An easy solution to this problem is to add some randomness on body motion control. But excessive modification of motion may interfere with plausibility, while insufficient modification may not make enough effects.

3) Third sub-impression is plausibility of interactivity of behavior. Human users expect somatic expressive artifacts to react quickly against cues given by users, but it is difficult to interrupt artificial body motion when the motion is made with less flexible motion data such as motion-captured data.

4) Forth sub-impression is plausibility on relationship of cues and reactions. Somatic expressive artifacts should make reaction with plausible reasons. The artificial computer-graphics dog made by Blumberg et al.[4] has an algorithm that makes actions responding to the dog's artificial desires and stimuli from the environment. Blumberg's intention is to make the dog behave plausible regarding ethological aspect.

Somatic expressive artifacts for entertainment use, however, are wanted to behave not ethologically plausible but expressive and playful. Accordingly, considerations on methodology to generate body movements as expressions will be required.

5) Fifth sub-impression is plausibility on fluctuation

Table 1: Advantage and disadvantage of artificial choreograph method

Method	Advantage	Disadvantage
Copying real animals' motion	Most plausible	Not interactive & adjustable
Designers' handmade motion	Plausible to some extent	Adjustable & interactive to some extent
Algorithmic motion generation	Spontaneous	Theories are ambiguous or unknown.

of characteristics among artifacts. Similar to plausibility problem of fluctuation of motion patterns, diversity of behavior characteristics will be required when plural somatic expressive artifacts behave together.

Bates[2] reports on impression of behavior of a computer-graphics artifact controlled by an algorithm with unintentional dugs. Despite awkward body movement, this behavior make the audience feel characteristic of the artifact.

6) Sixth sub-impression is plausibility on cultural factors. Some behaviors of humans have fixed pattern and fixed meaning that depends on cultures. Moreover, some animals have fixed expression that depends on species and/or regions.

The mechanism of emerging of fixed expressions is explained by Tinbergen's ritualization theory[17]. The transformations of non-display behaviors into display behaviors are results of fortuity and natural selection. By chance, a strange behavior may become a common token among the species that has a special meaning.

Similarly, the unexpected strange behaviors reported by Bates may acquire special meaning by chance. But ritualization process requires tremendously long time, so it is not practical to employ learning algorithm that simulates ritualization process in order to generate and adjust expressive behavior of somatic expressive artifacts.

1.2 Advantage of algorithmic chreography

This paper presents an automatic method of expressive body movement generation. This method mainly concerns the problems of producing plausibility on body motion, motion fluctuation. In addition, this method will facilitate solving the problem on interactivity, because it is does not require fixed motion patterns.

The conventional methods to synthesize life-like body movement of somatic expressive artifacts can be summarized by classifying as the following 3 strategies: 1) copying real animals' behavior by using motion capture systems, and 2) using designers' handmade motion data, and 3) automatic choreographing by algorithms.

Each method has advantages and disadvantages as shown in Table 1. Among the advantages, especially interactivity will be more required for choreographing somatic expressive artifacts. In the near future, real-world service robots will work with humans more closely. Moreover characters in video games and human-like interface agents will face humans and interact more spontaneously. Interactivity of artificial agents will be required these spontaneous interaction with humans, and this is the reason of demand for automatic body movement generation methods.

Among the 3 methods shown in Table 1, enough interactivity can be given only by algorithmic choreography. There are some conventional techniques of algorithmic choreography. However, most of the conventional automatic choreography methods were made in ad hoc ways without enough theoretical knowledge on the relationship between psychological state and body movement.

Such theories can be found in the discipline of ethology, dance art, and therapeutics dance research. Somatics is the name of these studies.

In this paper, the author employs somatics theories on body movement in order to build an algorithm for automatic life-like body movement. These theories are conventionally used to analyze the psychological state from body movement. In other words, these theories provide the maps from body movements to psychological state. The author tries to use these maps in an inverse way: from psychological content to body movement of somatic expressive artifacts.

This paper is composed with introduction about somatics theories and engineering interpretation of the theories. Furthermore, it reports an implementation example of an automatic choreography and an experiment of measuring impressions of generated body movements in different movement rhythm.

2 *Somatics:* theories of relationship between psychological state and body movement

2.1 Theories on body movement control system in real animals

The historic flow of somatic theories can be classified as shown in Table 2.

One of the most classic and most difficult problems on controlling movements of life-like shaped bodies is excess of the degree of freedoms (DoF) of the bodies. Bernstein[3] said it is unnatural to suppose

Table 2: Hypotheses on DOF problem (How to control DOF-excess body)

DOF Problem	Theorist	Constraint Framework Hypothesis
as control problem	Bernstein	Assumption of *'coordinated structure'*
	von Holst	*'Magnet effect'* synchronization
on expressional body movements	Darwin	*'Fighting/Retreating'* bipolar structure
	Laban	Detailed Darwinian structure
on body DOF	Cohen	Evolutional movement patterning
on rhythm DOF	Hunt, Kestenberg	Designated tension pattern stereotypes

Table 3: Cohen's Evolutional Patterning of Body Movement

Pattern Name	Classification on animals	Order on body movement
Disorder	No nerve connection	No synchronism
Breath	Multicellulars	Synchronism
Core-Distal	Symmetric Bodied Animals	Radial symmetric movement
Head-tail	Coelomata (fishes, insects, etc.)	Tension propagation from head to tail
Upper-lower	Amphibians	Tension separation into upper/lower half bodies
Homo-lateral	Reptiles	Tension separation into leftr/right half bodies
Contra-lateral	Mammals	Left-right crossed tension separation

that a mind can control all parameters of the body movement independently, and there must exist some anatomic constraint mechanisms (named 'coordinated structure') to reduce DoF. Following Bernstein, von Holst[9] reported phenomenon named 'magnet effect': movement of a limb effects on the movement of the other limbs. Magnet effect is caused by the nervous connectional structure.

Prior to them, Charles Darwin[6] found more detailed mechanism of the constraints regarding expressional body movement. According to his theory, there are 2 stereotypes in bodily expression, namely fighting form and retreating (or 'indulging') form. The stereotypes can be defined as traits of motion and posture. The stereotype of fighting, for instance, can be defined as quick and straight motion and enlarged and rising body posture.

Rudolf Laban[12, 1] made his theory by entering into the detail of Darwinian stereotypes. Eventually Laban and his followers made new method called Laban Movement Analysis (LMA) that analyses psychological state of a human by measuring body movement.

Since LMA method is too large to describe in this paper, the author describes only the theories developed by Laban's followers, namely Cohen, Hunt, and Kestenberg. Overview of LMA is described in [13].

2.2 Cohen's constraint system on DoF of body

Comparing body movement pattern of animals, Cohen[5, 8] found the relationship between evolutionary state and mechanical constraints on body movement shown in Table 3.

Frogs, for instance, control their body by dividing muscular tension control into *upper and lower* half bodies. Horses are more evolutionaryly developed, so that they can control their body in the frog's way when they run very fast, namely gallop.

Table 4: Hunt's stereptype of muscular tension rhythm

Rhythm Name	Periodicity	Acceleration
Undulate	Strong	Low
Sustained	Weak	Low
Restrained	Weak	High
Burst	Strong	High

Moreover horses can select more complicated control ways. In 'homo-lateral' (or 'ipsilateral' in terms of biology) control mode, tension control is separated into right and left half bodies. As a result, left forelimb and left hind leg moves together. Likewise, right forelimb and right hind leg moves together. The running of horses in homo-lateral control mode is named *walk*.

When a horse walks little faster (i.e. *trot*), it moves right forelimb and left hind leg together, and moves left forelimb and right hind leg together. This right-left crossed tension control is named *contra-lateral* mode.

As shown in Table 3, there are 7 stages of body constraint patterns in evolutionary and developmental process. Animals can use more complex control modes when they are evolutionaryly complex species and they developed enough.

2.3 Muscular tension rhythm stereotypes

Temporal pattern of muscular tension can be well artificially controlled when a human pay consciousness on it. In ordinary body movements, however, the mover does not have to pay conscious. It is considered that there are some tension pattern generators in nerve system [14]. The generators are called central pattern generators (CPG). Most of ordinary body

Table 5: Kestenberg's interpretations of body movement rhythms

Rhythm Name	Darwinian classification	Temporal pattern of muscular tension	Psychological state	When appears on human infant
Sucking	Indulging	Small sine wave	Absorbing affection	Birth –
Snapping/ Biting	Fighting	Small triangle/ trapezoidal wave	Attention to something	0.5 year old –
Twisting	Indulging	Small sine + drift	Intention on locomotion	9 months old –
Strain & Release	Fighting	Large long bang-bang wave	Concentration and relinquish	1 year old –
Runnging & Drifting	Indulging	Drift	Controlling continuity of movement	2 years old –
Starting & Stopping	Fighting	Bouts and intervals	Decision on starting and stopping	2.5 years old –
Swaying	Indulging	Small long sine wave	Enjoying pleasure	3 years old –
Surging & Birthing	Fighting	Large long sine wave	Enduring pain, trying to escape from pain	3.5 years old –
Jumping	Indulging	Large short sine wave	Excited	4 years old –
Spurting & Ramming	Fighting	Large short triangular wave	Intentional violence, hostility	5 years old –

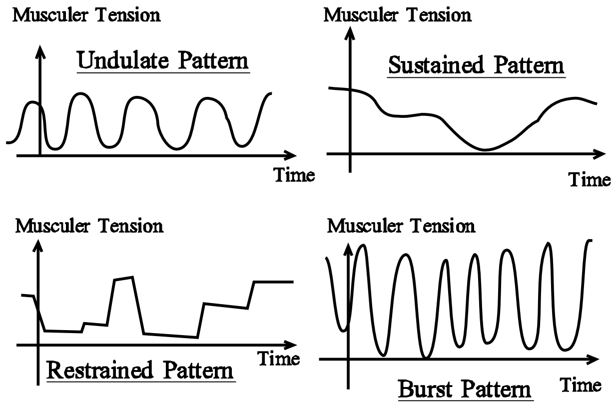

Figure 1: Temporal patterns of Hunt tension stereotypes

movements are reciprocating. CPG provides oscillation waves that become reference signals of muscular tension.

From many observations on movement of animals and humans, somatics researchers got an idea that the number of CPG patterns is limited, and stereotypes of CPG patterns exist.

The hypothesis made by Valerie Hunt has 4 stereotypes of CPG rhythm patterns shown in Figure 1. The patterns can be interpreted mathematically as Table 4. The keys of Hunt's categorization are periodicity and acceleration (or differentiability) of patterns.

There is another hypothesis with more detailed categories. Observing body movement of babies, Judith Kestenberg[11] found that the oscillation patterns of CPG signals can be classified into 10 stereotypes shown on Figure 2. Each pattern has relationship to psychological state and developmental state shown in Table 5. While growing up, a baby gradually

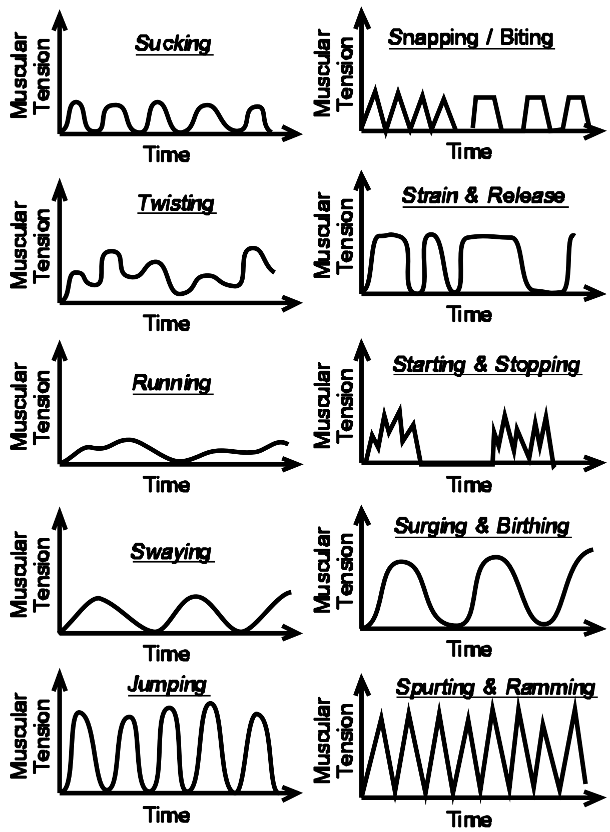

Figure 2: Temporal patterns of Kestenberg tension stereotypes

acquires more varieties of muscular tension pattern that reflects more complicated psychological state.

2.4 Agreements with biological facts

Some biological experimental facts support Cohen's theory on DoF constrain and Kestenbergs theory on motion rhythms.

Shik et al. [16] succeeded to control walking of a cat by stimulating its mid-brain electrically. The cerebrum of the cat was eliminated, and its mid-brain was stimulated by DC electric voltage.

Even though the DC stimulus was constant, the legs of the cat moved in reciprocation. Voltage of the stimulus changed the rhythm of muscular tension. Low voltage stimulus caused small amplitude and low frequency rhythm. Higher voltage, in contrast, caused large amplitude and rapid frequency rhythm.

This fact implies that the CPG exists at the downstream below mid-brain and generates tension rhythm patterns. The cerebrum can select tension rhythm patterns by stimulating the mid-brain. The stereotypes of tension patterns are prepared by CPG structure, and only parameters such as amplitude and frequency are subjects to cerebrum's control.

Schöner et al. [15] found that humans can not move right and left hands separately in rapid alternating motion. Humans can move them only right and left hands together in very high motion. Note that the CPG can make very rapid alternating motion rhythms when the DoF constrain system is failing to distribute the tension control signals separately. This fact supports the advantage of modeling body control system with separation of CPG and DoF constrain system.

3 An implementation example of algorithmic choreography

3.1 Purpose

In order to show how to interpret the theories from engineering viewpoint and how to realize a choreography algorithm based on the theories, an example of practice is reported in this section.

3.2 Equipmental Setting

Because of the facility for realization of movement display, the implementation is done in 3-dimensional computer graphics world. The computer graphics software is developed with OpenGL libraries.

A body shown in Figure 3 is modeled after an ordinary life-like body. The body has 12 joints. Each joint has 2 DoFs on bend directions, so the body has 24 DoFs.

In addition to this, another body with simplified limbs is also created as shown in Figure 4. This body has 14 DoFs.

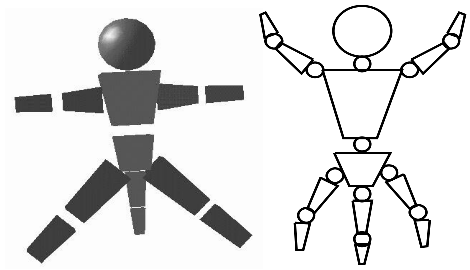

Figure 3: Kinematic structure of a CG model with bend-able limbs with 12 joints and 24 DoF

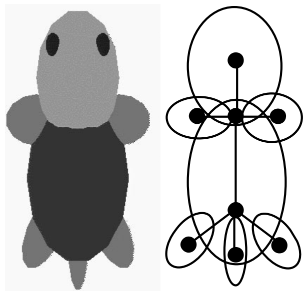

Figure 4: Kinematic structure of a simplified CG model with a fixed pelvis and 7 free joints. Total DoF is 14.

The movement generation algorithm is demonstrated on both body structures.

3.3 Interpretation and implementation

3.3.1 Strategy

As shown Figure 6, when the evolutionary/ developmental state and psychological state of the agent are given, proper muscular tension rhythm and body movement constraint are determined according the hypothesis of Cohen and Hunt (or Kestenberg). Then, the algorithm distributes the tension signal on each muscle.

This methodology of movement generation is ruled by evolutionary, developmental and psychological relationships described in the previous section. Therefore, the movement generated will reflect the character's evolutionary, developmental and psychological states to some extent.

3.3.2 Implementation of Bernstein's 'coordinated structure'

According to Bernstein's idea, 24 DoFs that the body has is too many to be controlled for a real-life mind. The muscles should be grouped into 'coordinated structures'. Flexure muscles that are directed cooperative direction are grouped into same DoF unit as shown in Figure 5.

Six DoF units are employed, namely chest-head bending, bending around each shoulder, bending around each hind leg and tail bending.

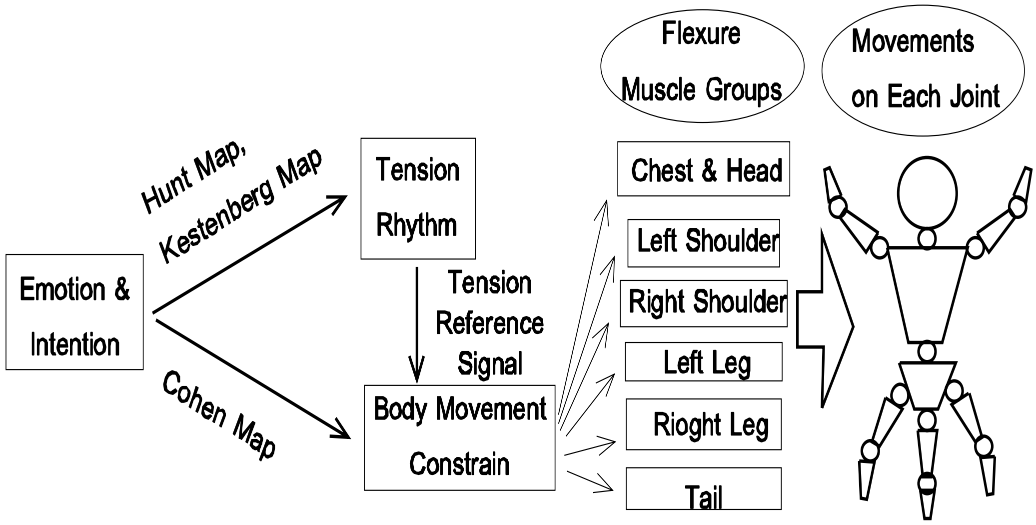

Figure 6: Mapping from emotional and intensional state to body movements

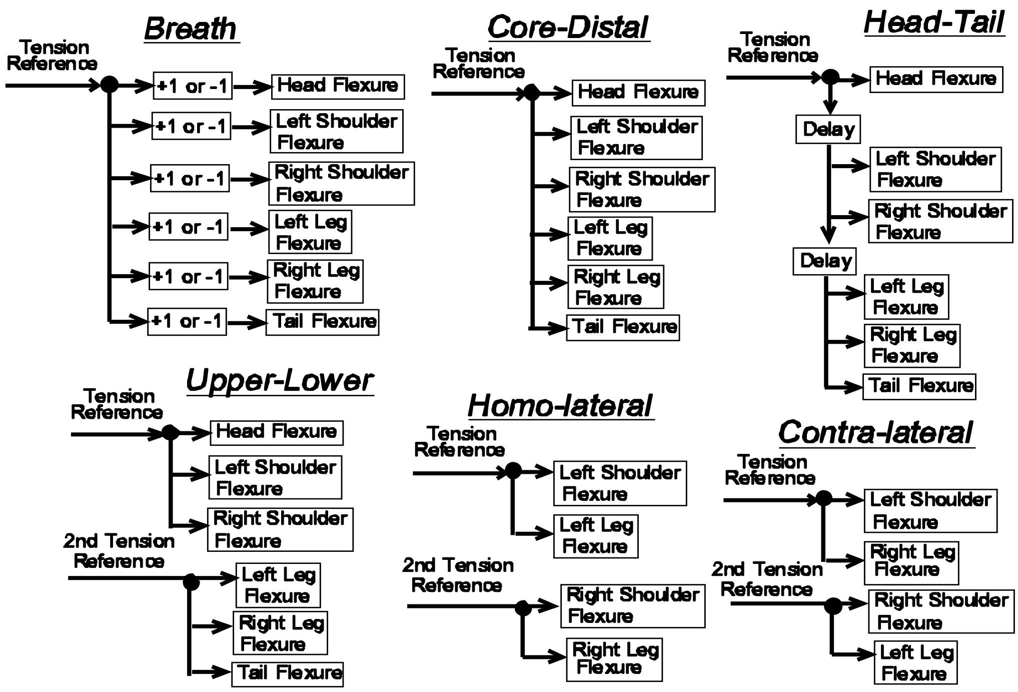

Figure 7: A realization of control diagrams of Cohen patterns

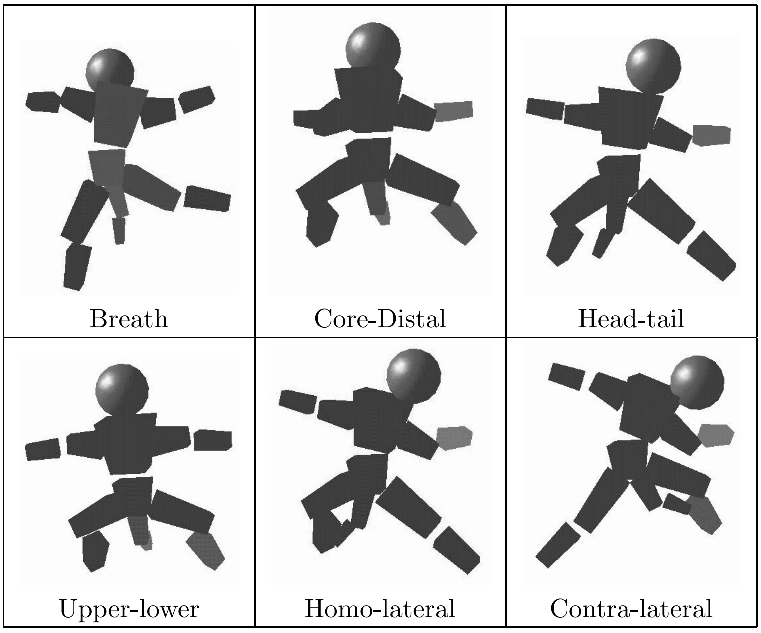

Figure 8: Cohen evolutional phases of body movement pattern

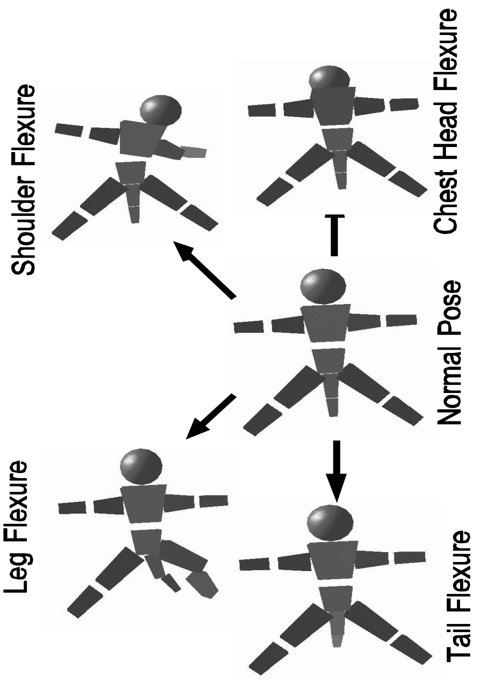

Figure 5: Flexure elements of experimental CG model

3.3.3 Implementation of Cohen's movement constraints

Cohen's movement constraint is simply a matter of distribution of tension signal. Figure 7 shows the implementation on control block diagrams.

3.3.4 Implementation of Hunt and Kestenberg tension rhythm stereotypes

Hunt and Kestenberg tension rhythm stereotypes shown in Figure 1 and Figure 2 should be interpreted into mathematical terminologies. Hunt's stereotype can be interpreted as wave with periodical terms (like sinusoidal wave) and stochastic drift terms. Table 5 contains examples of mathematical interpretations of Kestenberg's stereotypes.

The rhythm generation is implemented by basic mathematical functions of C language.

3.3.5 Results

Figure 8 shows still images of automatically generated body movement in Cohen's 6 body constraint mode. The experimenter selected evolutionary/developmental state and emotional state of the character, and inputs them to the system. Then the system processed and generated body movements as shown Figure 6.

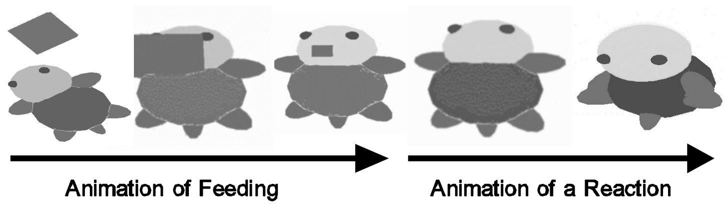

Figure 9: Animation of feeding scene and one of the 4 reactions

4 Experiment on measuring the relationship between Hunt's rhythm stereotypes and their impressions

4.1 Purpose

This section reports a result of expressions of typical body movements that work in Hunt's tension rhythm stereotypes. Besides the somatic theoretical thoughts described above, the effectiveness of the body movement generation methods should be tested in an experiment.

The experimental hypothesis is the following: movement expressions in animated characters can convey emotional impressions by selecting proper tension rhythms and patterning according to theoris of somatic modelling.

The effectiveness of automatic movement generation method can be considered as effectiveness on expression. It has temporal aspect and geometrical aspect. The temporal aspect means plausibility and expressiveness of rhythms and timings of the movement. Likewise, the geometrical aspect means plausibility and expressiveness of postures and paths of the movement.

Because of the size limitation on this paper, the author reports only an experiment on the expressiveness of movement rhythms. (Other similar experimental reports can be found in [13].)

4.2 Procedure

Overview of the experimental procedure is as the following:

1) The number of subjects is 11. Each subject is shown the computer graphics character and objects as Figure 10. In the screen, there are 4 objects in the left that are explained to each subject as foods for the character. The character has no movement.

2) Each subject is told to select one of the foods by clicking it. After clicking a food, animation begins as shown as Figure 9. The wall disappears, and the selected food moves and fade away into the character s mouth, so that it seems eating the food.

3) After eating, the character starts body movement as reaction. Unique reactive movement is prepared for each food.

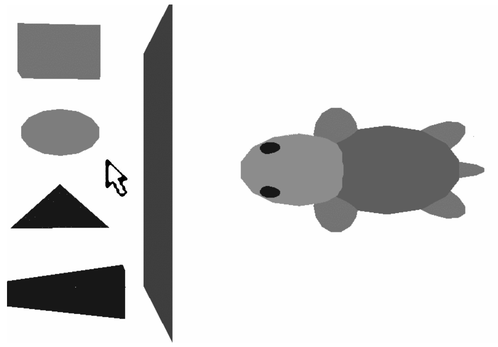

Figure 10: Initial image of the experiment

1) When you feed the food at upper-most position,
Question-A: Does it seem as if the character calmed down?
Calmed Down -- Relatively Calmed Down -- Relatively Excited -- Excited
Question-B: Dose it seem as if the character is feeling pleasure?
Feeling Pleasure – Relative Pleasure -- Relative Displeasure – Feeling Displeasure

2) When you feed the food at 2nd position,
<the same questions as 1) >

3) When you feed the food at 3rd position,
<the same questions as 1) >

4) When you feed the food at 4th position,
<the same questions as 1) >

Figure 11: Experimental Questionnaire Sheet

In order to reduce the number of comparisons in the experiment, 4 stereotypes of Hunt's classification are employed.

The reactive movements are driven in *Core-distal* type body constrain and Hunt's tension stereotypes. The food in the upper-most position causes reaction with *Undulate* rhythm. The 2nd food causes *Burst* rhythm. The 3rd food causes *Restrained* rhythm. The food in the lower-most position causes *Sustained* rhythm.

The order of selection is free, and redoing of selection is allowed.

4) Each subject is told to watch the reactive movement for 5 seconds, and answer the impressions of the movement by filling the questionnaire sheet shown in Figure 11. The questionnaire has 2 scales of impressions. One is the scale with 4 degrees to answer about

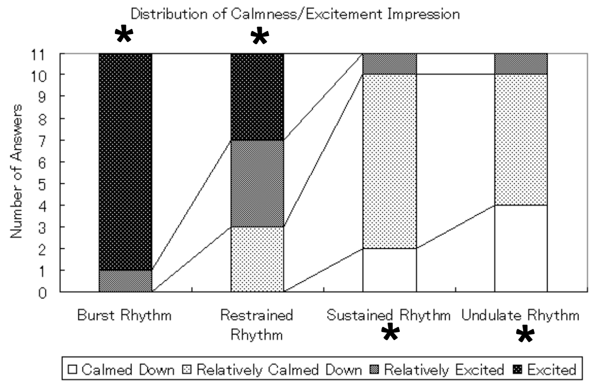

Figure 12: Answer distributions on 'calmed down' vs. 'excited' impression

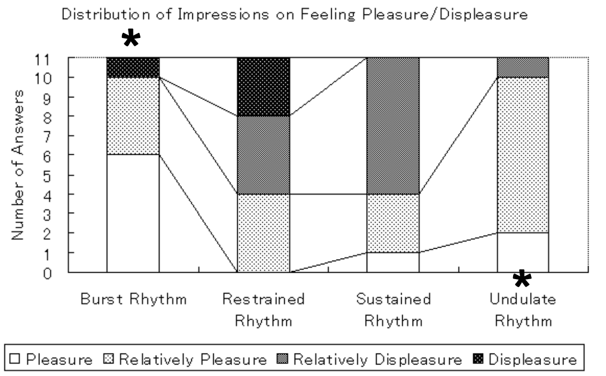

Figure 13: Answer distributions on 'feeling pleasure' vs 'displeasure' impression

calmness vs. excitation of the movement. The other scale is also with 4 degrees to answer the impression about whether the movement seems with pleasure or displeasure.

5) After collecting answers, Mann-Whitney's U-test is applied on distributions of the answers. Significance level is set to 5 %.

4.3 Results and Discussion

Figure 12 and Figure 13 show the distributions of all answers. Significant tendencies are marked with *.

According to Figure 12, Burst rhythm and Restrained rhythm produced impression of excitation. This means that movements with large acceleration produce impression of hastiness. In contrast, Sustained rhythm and Undulate rhythm produced calm impression.

Figure 13 shows Burst rhythm and Undulate rhythm produced strong impression that the character moves with pleasure. This means that smooth and periodical body movements are signs of pleasure.

Figure 14 summarizes the results. Each of Hunt's 4 stereotypes of tension rhythms fortunately has unique pair of calmness and pleasure impressions. That implies the possibility of emotional expression by showing body movement with proper tension rhythm.

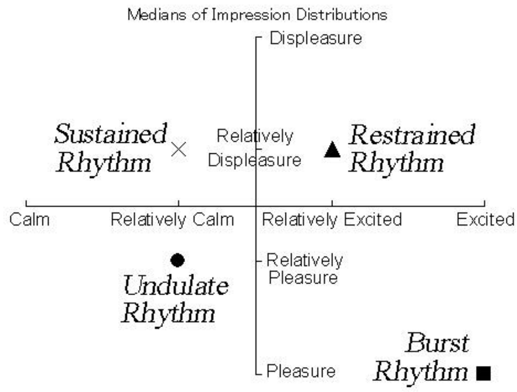

Figure 14: Medians of impression answer distributions of 4 Rhythms

5 Summary and Conclusion

The methodology on algorithmic generation of proper and plausible body movements is described with an implementation example and an experiment on performance of rhythmic body expression.

This methodology is based on Cohen's and Kestenberg's theories that describe the relationship between evolutionary, developmental and psychological states and body movement. Therefore this method can be regarded as a theoretical way to generate typical body motion that produces life-like impressions and emotional impressions.

An implementation is organized to show the utility of this methodology. The key concepts of the theories are interpreted into engineering terminologies. Also a scheme of choreography algorithm is described with block diagrams.

In the experiment, movement expressions succeeded in conveying emotional impressions by selecting proper tension rhythm from Hunt's stereotypes.

In future work, evaluation of expression accuracy, harmonization with other modalities (voice, facial expression, and so on) and harmonization with context, should be studied.

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