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Sharing descriptions of movement

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Abstract

In this essay the authors report on the findings of the one-day workshop called Choreographic Computations: Motion Capture and Analysis for Dance held at IRCAM (Institute for music/acoustic research and coordination) in Paris in June 2006. The focus of the workshop was on new innovations combining motion capture and computer-based techniques with choreography and performance. An international group of artist programmers and dance makers who are bringing complex algorithmic procedures into alignment with choreographic creation were invited to give presentations and discuss, with each other and the invited audience, the shared understanding of movement and gesture they are developing.

Keywords
choreographic computation
gesture follower
dance
EyesWeb
Isadora
artificial intelligence

Background

On 4 June 2006, we organised a one-day workshop called *Choreographic Computations: Motion capture and analysis for dance* at the Institute for music/acoustic research and coordination (IRCAM) in Paris in the context of the annual New Interface for Music Expression (NIME) conference.[1] Established in the 1970s, IRCAM has remained singularly dedicated to the connection between research and creation with a focus on music.[2] Today there exist several departments working together under three headings: research, creation and transmission. Under research there are several groups, including the Real-Time Musical Interactions Team investigating 'real-time computer technology for digital signal processing and machine learning for music, sound and gesture'.[3] Bevilacqua has been directing the gesture analysis research of this team since the end of 2003.

Our motivation to organise the workshop arose from an overlap of different events. In December 2004, we participated in a workshop at the Monaco Dance Forum and discovered a similar approach to cross-disciplinary research involving movement, dance and science. In September 2005, we took part in a small group meeting organised by Antonio Camurri (InfoMus Lab, Genoa) on the topic of Motion Analysis Research and Dance. This gathering marked the start of efforts to establish a network of research institutes working on the theme of movement analysis within interdisciplinary arts and science research.[4] One of the commitments made by the group was to continue meeting in the context of other events, such as the EyesWeb Week organised by Camurri and his team in February 2006 and our workshop organised at the start of NIME 2006.[5]

Focus and objective

The focus of *Choreographic Computations* was on new innovations combining motion capture and computer-based techniques with choreography and performance, an area in which we felt there were a group of artists breaking new ground. The unique dimension we wished to emphasise in their work was the bringing of complex algorithmic procedures into alignment with choreographic creation and the development of a *shared* understanding of movement and gesture. This was referred to in the announcement as 'carving out fresh territory for correspondences between choreography and computation'. The organisation of the workshop was intended, at least in part, to test how far we were correct in our assumptions' and to help establish what a shared understanding of movement and gesture might comprise. The event was also meant as an opportunity for the artists themselves to meet and perhaps gain stimulation from each other's work. Since it was our observation that they had similar goals, but were using different approaches, we hoped there would be cross-fertilisation of methods.

The artists and researchers we invited to present their work were Antonio Camurri, Mark Coniglio, Marc Downie, Myriam Gourfink, Rémy Muller and Dawn Stoppiello.[6] Each presentation lasted from 30 to 45 minutes with time reserved after for discussion. The audience for the workshop comprised approximately forty individuals from a wide range of backgrounds, artists and scientists united through their interest in movement research and gesture analysis. The atmosphere in the single room was intimate and informal; the presentations were made from one side of the room without a stage, and the audience engaged in discussion at the end of each. However, in the following brief report, we reserve our reflections primarily to the comments and statements made by the presenting artists. All comments in quotes without a reference are taken from the transcripts.[7]

Introductory presentation

The aim of the introductory presentation by deLahunta was to give some context for why these artists were working in new and unique ways. We were specifically interested in how their projects brought the computer and programming into play as a creative partner in connection to making dances. And we were looking at the possibility of the development of a shared understanding of movement and gesture, shared by both the choreographer/dancer and the computer specialist (software artist, engineer or programmer). However, there is earlier creative work that could be argued to have already explored these topics, provisionally weakening our distinction proposal:

- 1964 at the University of Pittsburgh, choreographer Jeanne Beaman and computer scientist Paul Le Vasseur made computer generated choreography using an IBM 7070 computer to randomly choose a sequence of events from a list of movements: rotate shoulders, hop, jump, fall, gallop, flex knee, rotate leg, walk with legs bent, move left arm, rise etc.[8]
- Another early pioneer of the convergence between choreography and computers was John Lansdown, an architect by training from London. He was particularly interested in the possibilities of 'artificial creativity' to use the computer as an autonomous composer, rather than support or augment the existing creative process.[9]
- There is Merce Cunningham's well-known connection to the development of and his subsequent creative use, still today, of the 3-D human figure animation software LifeForms. This is the support approach Lansdown was less interested in, but still shows a close link between choreography and computer at the level of the creative process.[10]
- Additionally, although there were no computers directly involved, many 20th century artists including choreographers worked at some point with rule-based or algorithmic systems; in dance we have the example of Trisha Brown and William Forsythe.[11]

While we accept that these approaches and projects made use of the computer (or computation) as part of the creative process and may have encouraged a shared understanding of movement and gesture, the artists and researchers we invited have been building and working with systems to analyse, recognise, learn, perceive, model and/or follow movement (or gesture) with the computer. Analysing and modelling movement has been a research trajectory in computer science since at least the late 1970s; hence most of the algorithms are already in existence.[12] But recent technological innovation, such as increases in memory capacity and processing power, has helped to put these approaches as instruments into the hands of artists. This we felt to be a clear departure from these earlier examples.

Now these systems, as evidenced by the work of the presenting artists/researchers, are being built in correspondence to a choreographic creative process, sharing an understanding of movement and gesture with dancers. This sharing occurs, at least in part, through the production of descriptions of movement in its own terms (as in physical) and in the symbolic abstractions that are necessary in order to use these computation techniques of gesture modelling, learning, following etc. We have coined the term 'co-description' to help frame this notion. However, as we have expressed already, the workshop was intended to test our ideas, and, in the following, we discuss some specific examples and in the conclusion will return to some of these issues.

Gesture follower research

Following the introduction, Bevilacqua described some of the gesture analysis research he has been directing with the Real-Time Musical Interactions Team. The main aim has been to establish methods for computing high-level parameters of movements similar to the ones used by choreographers in creation and performance (e.g. notions of movement quality, expressiveness and meaning). The background assumption was that a focus on high-level parameters could better facilitate the design and use of systems meant to interact with gesture. Another hypothesis of the research was that the use of interactive systems in the context of performing arts is usually more limited by poor real-time motion analysis techniques than by the motion capture hardware specifications.

One aspect of the gesture analysis research explored various mathematical techniques such as Machine Learning, the study of 'computer algorithms that improve automatically through experience'.[13] After some tests with techniques used to automatically extract features of motion capture data (for example Principal Component Analysis), the main research focus was directed towards methods to recognise and follow phrases using Hidden Markov Models (HMM), a statistical approach that models what we observe as the output of hidden states.[14] This approach relies on the idea of a 'learning' phase, when movement phrases are recorded and then processed by the computer using the HMM. This reveals parameters that are re-introduced into the system as a recognition schema, which is then applied in real-time to the movement phrase as it is performed again. The recognition schema is able to evaluate and report on the similarities between this live performance and the previously recorded and 'learned' examples. This works on the principle of probability theory by attributing a 'likelihood' rating that is continuously updated from the beginning of the performance. The likelihood is the results of the comparison between two examples, a high value reporting that the two phrases are performed almost identically and a low value indicating that the phrase are very different; this is one way we could say the phrases are 'recognized' by the computer.

An important point in this approach was to consider a gesture as a time-based process, instead of trying to recognise postures. This approach was developed not only with the recognition scheme in mind, but also aiming at the idea of performing gesture following, i.e. precisely indicating, 'where we are inside the phrase'. Such a capability is analogous to *score following techniques* developed for over 20 years in the computer music field including extensive development by researchers at IRCAM. Also using HMM, *score following* aligns the audio signal produced by a musician with the score he or she is playing and uses this information to connect to the electronic dimension of the music, putting the performer more in control of the 'possibilities of expressive performance'.[15]

Score following is intended to connect the computer system more closely with the high-level parameters of human performance and perception. However, it is automated on the basis of an existing musical score. The critical development of the *gesture follower* is that it does not work with a predefined score, but, interestingly, using the gesture follower induces the possibility of creating a score, which can be annotated.[16] This can be done manually by adding markers to highlight particular sections or transitions, in a timeline representation of the phrase. These annotation elements can then be used as an output of the gesture follower during the performance. For example, the markers can be used to segment in real-time the performed piece automatically.

Generally this particular proposed scheme of recognition/following enables the information to be extracted from the motion-capture data in direct correlation to examples given by the performer. The results of the gesture analysis are thus dependent on the information contained in the examples chosen in the learning phase. In this sense, this approach can be seen as an attempt to propose a 'context-dependent analysis'. One could speculate how such a system contributes to a decrease in the gap between the choreographer's understanding and the programmer's understanding of the process by gradually introducing observations of the dancer as information at key points directly into the digital tracking/analysis loop.

Multimodal versatility

Against the backdrop of the IRCAM research approaches, Antonio Camurri presented recent developments in scientific and technical research his team in Genoa has been conducting, for many years. They are the developers of the software EyesWeb for the real-time analysis of expressive gesture using state of the art computer vision and other techniques. This approach is significantly different to the ones based on 3D optical motion capture systems that use reflective markers and multiple cameras. EyesWeb operates typically without markers using one or two video cameras and integrating multimodal inputs (video, sounds, sensors etc).[17] Camurri gave an example of a recently developed approach that can transform any object (e.g. a table) into a tangible interface, where the location and the type of the touch is sensed using a set of microphones/accelerometers directly attached to its surface.[18] This processing is achieved with EyesWeb and can be complemented by an additional video input, allowing for the multimodal measurement of different ways of touching and interacting with the object.

Notably, in parallel with development of Eyesweb, a consistent framework has also been developed considering separate levels of gesture analysis from low to high-level parameters.[19] Typically, various analysis modules allow for the determination of large set of parameters related to the silhouette, point trajectories, spatial and temporal statistics (such as average spatial occupancy) to parameters related to movement qualities (for example rigid vs. light gestures).

However, the team's research goes beyond the development of software and is more generally dedicated to the study of non-verbal communication for which dance is considered to provide essential case studies. Particularly, research topics reside in the question of how expressive cues between dancers, or between dancers and audience can be measured. An important effort is made by the group to validate the relevance of the proposed analysis with experiments in various music and dance contexts. Additionally, collaborations with psychologists are being pursued, and studies include the correlation of parameters with basic emotion or more recently the study of empathy between musicians performing together.[20]

Several examples were demonstrated during the talk, in particular, where parameters have been inspired by the theory of effort developed by movement analyst Rudolf Laban in the early 20th century.[21] An important part of their development work tends to answer principally to the question of 'how is the gesture performed' instead of 'what is performed', and Laban's effort theory provides useful descriptions for them to use in this task. The EyesWeb software is used by artists and researchers worldwide, including artists presenting here today. It is freely distributed via the InfoMUS lab's website, and Camurri and his team are in constant development, frequently releasing new versions with recently developed modules for analysis.[22] If, as we are suggesting, choreographers are poised to collaborate with computer specialists (artists or scientists) in a shared field of movement/gesture analysis, Camurri's group in Genoa is producing an invaluable resource.

FLUID thinking images

Marc Downie is an artist and artificial intelligence (AI) researcher and programmer, whose work is inspired by natural systems and a critique of prevalent digital tools and techniques. His artworks comprise interactive installations, compositions and projections. Downie began his presentation by describing his interest in a 'new kind of picture' created by 'autonomous agents with their own bodies, their own perception systems and own ways of choosing what to do'. These software agents are programmed as separate systems capable of analysing and interacting with data coming from different sources, such as motion-capture.[23] Inspired by their capacity to understand and respond to their surrounding data environment, Downie and his collaborators have called the new kinds of pictures the agents make 'thinking images'.[24]

In 2001, Downie joined digital artists Paul Kaiser and Shelley Eshkar to create *Loops*, in collaboration with choreographer Merce Cunningham. Kaiser and Eshkar had previously collaborated with Cunningham on projects using 3-D motion-capture animation.[25] *Loops* used motion-capture to record the movement of Cunningham's 1971 solo dance for his hands, and Downie applied his knowledge of agent-based AI and real-time graphics to create a 'colony' of 'autonomous digital creatures' that would interact with this data.[26] This project encouraged the artists to accept a commission to collaborate with choreographer Trisha Brown on a new creation, which would use a motion-capture system during the performance.[27] Not only would Downie have the opportunity to press his agents into a relationship with real-time motion-capture data (*Loops* had been pre-recorded), but also to program his new agent colony at the same time as the dance was being choreographed.

A major challenge was realised when he could not write code fast enough in the rehearsal studio to respond spontaneously to what the dancers were doing. Finding himself taking 'fewer and fewer risks', he wrote a tool called FLUID to interact with his own code. FLUID was designed to move easily between debugging and writing code and was able to remember everything that happened during a working session. This memory ability made it possible for Downie to name unexpected occurrences that might happen during a rehearsal so that he could call upon them later. He said, 'Trisha can, with a single instruction transform a segment of choreography because she delegates the problem solving to her dancers (…). I needed that ability to do that in my own practice'. FLUID was his solution to this need. With FLUID and his agent-based approach to making interactive art, Downie challenges the dominant paradigm embodied in the term 'mapping' and its related aesthetics.[28]

The collaborative dance work came to be titled 'How long does the subject linger at the edge of the volume…', a comment Trisha overheard someone on the motion-capture team make. Premiering in April 2005, the piece was 3 years in the making. When asked to identify a few specific points when Trisha and he connected during the creation process, Downie remarked that it was in the 'naming of things' that this was perhaps most explicit. This naming process was part of developing a common enthusiasm and language for what they were doing. Other cooperative decisions were made in silence, e.g. he showed her the Triangle image and the next day she came with a solo inspired by it.

In fact, the Triangle image opens the piece. [see Figure 1] When the dancers first step out and start across the stage from stage right to left the Triangle appears and starts 'hitching a ride on the dancers (…) sending out lines and retracting them leaves traces on its own body'. It does this by searching for motion-capture markers on the dancers. The goal of the Triangle is to get from stage right to left following the dance, always making it across because it has 'learned a rough set of heuristics about where and when it should connect and let go of the dancers'. The Triangle agent has 'seen the dance before', but it still has to make new decisions of every performance about when and how to connect to it. The audience watches this 'thinking image' projected on a large scrim hung in front of the dancers; the stage behind is well lit so that one can easily see both the projection and the dancers.

With self-directed agents like the Triangle and Weaving (another agent that is part of the dance), Downie makes a strong proposal for a new way of thinking about the aesthetics of interactive art making. He doesn't consider his agents as mapping input to output. Rather they display 'a set of expectations that are intentions about how the world works and how they will act in the world'. Downie's methods are computationally complex, but his terms and descriptions evoke strong connections with choreographic body-based movement practices. The creation of his new tool, FLUID, shows his commitment to engaging with the dance making process. This combination: a rich new repertoire of descriptions to stimulate and be stimulated by choreographic practice in combination with a cooperative understanding of creation processes is why this collaboration stands out as a strong indication of where computation and choreography might go together in the future.

Following and resonance

Paris-based choreographer Myriam Gourfink has developed a unique body of works. She is known for her approach to movement material in which she explores an expanded world of time with extremely slow and often small movements. She was invited by IRCAM to work on a project using the gesture tracking and analysis systems, the Performing Arts Research Team and the Real-Time Musical Interactions Team were developing.[29] After a preliminary phrase of research, Rémy Muller was the member of the IRCAM team selected to work closely with Gourfink on her dance piece titled 'This is My House', which premiered in 2005 at Quimper, France.[30]

'This is My House' is a performance in which the movement of five dancers is recorded using a variety of sensing devices and then analysed in the computer. The result of the analysis is used to trigger a change in a written score displayed on video screens, which the dancers are able to see while they are performing. [see Figure 3 / but please place 3 after 2] The scenography has been uniquely constructed to make this reading while performing possible by positioning twelve screens on the grid directly above the dancers. The movement is slow (which helps make the recording, analysis and triggering possible) and often performed on the floor, and so it is relatively easy for the dancers to see the changes on the screen. The written score uses symbol notation developed by Gourfink inspired by Labanotation. [see Figure 2]

This is a collaborative work that illustrates the shared understanding of movement and gesture mentioned previously, and we can use it to elaborate on various aspects of co-creation in this context. Because Bevilaqua's team had developed some of the concepts for analysis prior to inviting Gourfink to work with them, an initial fit with her unique choreographic approach had to be found. After a series of experiments, Gourfink and Muller eventually saw the possibility of using the gesture recognition and following system to allow the performer to modify the 'pre-written' dance. However, the co-creation had still to be realised/implemented in the computer, and it is in this process that the concept of shared understanding can be explored.

Muller commented that Myriam wrote the scenario and he 'just made the implementation', through the development of the appropriate software elements. However, in his description of the fine-tuning of the system he set up, there is an indication of a deeper process. Resonance or synchronicity between dancers was one of the properties of the dancers' movement the analysis system was built to recognise. Muller said, 'I spent some time to find the range it made sense to talk about "resonance" between dancers. (…) The system doesn't give an answer that isn't really close to what we see on stage'. Tuning the system to the appropriate threshold for the recognition of resonance within the context of the live performance required Muller to identify with what was working, artistically, on the stage. Gourfink and the dancers are the main arbiters of the space of the stage, but Muller's intuitive grasp of what works and what doesn't informed his adjustment of the system.

The outcome of the collaboration between Gourfink and Muller is a dance that is dependent on the computational input for its performance. The network of relations between movement sensing, the four types of analysis being performed and the triggered notation score on the screens, subsequently modifying the movements, is such that this is a work that is the same but new each time it is performed. This makes it arguably an 'open work' that is co-conducted by different agents, not the types of agents that have their own 'thinking' like Marc Downie's, but agents that depend on the analysis of the performance in relation to a set of written rules.[31] In the creation of 'This is My House', choreographic and computational thinking have settled into a particular correspondence, one we feel deserves closer study. It sets important precedents through retaining and magnifying to some degree the rigorous aesthetics of Gourfink and simultaneously demonstrating the value of the gesture analysis systems the IRCAM team has created.

Gestures and lines

Mark Coniglio and Dawn Stoppiello are the co-founders and directors of Troika Ranch, a performance group that has integrated dance, theatre and interactive digital media in their work since the early 1990s, longer than any of the other collaborations presented today. Coniglio is notably the creator of Isadora, a real-time video processing software used as a creative and performance instrument by artists worldwide.[32] Troika Ranch worked for several years with the 'MidiDancer', a wearable device Coniglio first built in 1989 that measures the angular change at several joints on the dancer's body. This information was sent over a wireless link to a computer where the data was used to control a variety of media events, e.g. sonic, video, lighting and/or robotic.

In 2003, Coniglio began to investigate a new system for measuring and identifying the quality of dancers' movement. In his words 'striving to match the complexity embodied by the live dancer using the quality of movement as a source of media control'.[33] After a period of research, Coniglio settled on using EyesWeb, the software mentioned earlier, that can use a single camera to track the silhouette of the dancer. It superimposes a 12-point skeleton onto this silhouette (head, shoulders, elbows, wrists, top of pelvis, knees and ankles).[34] [see Figure 4] EyesWeb then sends information about the pathway of each of these points to Isadora where the information is analysed and 'mapped' to dynamic graphic effects (and other forms of media). The system does not have the accuracy that an industry standard 3-D motion-capture system does, but it gives the same result every time. This makes the software suitable for Coniglio's research into sensing qualities of movement, and the overall setup something they could easily tour on the road.

Now that Coniglio could get the point pathways into Isadora, he started to visualise them as simple lines being drawn in space and projected on the screen. These dynamic lines, drawn (as on-screen projections) while the dancer was moving, served as the next step in Coniglio's movement analysis research. He started to break the lines up into smaller parts in real-time, segmenting them as a way to analyse them for simple properties such as degree of curvature, velocity and complexity.[35] A change in movement or gesture was automatically recognised by the computer as a change in the properties of the line and vice versa, and notably this was taking place in real-time.
Coniglio began to explore what he could do with the information derived from this analysis of the line/gesture. Through the segmentation process, certain properties of the gesture were initially isolated, and these could be recombined in a variety of ways, which Coniglio felt avoided some of the problems of one-to-one direct mapping Downie had discussed critically. The output and effects (in image and sound) derived from the gesture analysis component of the work was, in Coniglio's opinion, approaching the quality of the actual gesture to which the analysis was being applied. [see Figure 5]

The line has always been a provocative and effective tool for the artistic imagination in visual arts, as from its simplicity profound qualities emanate. But the combination of analysis and understanding its expressivity may have been best accomplished by visual artist Paul Klee in 1925, who, in his Pedagogical Sketchbook, defined and analysed the primary visual elements (including lines) and ways in which this analysis could be applied.[36] One might consider Coniglio's approach as bringing an important level of embodiment to Klee's thinking, engaging computation in the process of understanding the line and through this the comprehension of what a gesture is. The question is: does this take us a step closer to the idea of a shared understanding of movement?

Summary and conclusion

As mentioned earlier, the workshop was intended in part to test our assumptions about this new approach to the connection between computation and choreography. The diversity of the presentations, in terms of aesthetics, modes of working and production conditions, makes it difficult to return to some of our generalisations. For example: the access Marc Downie and Trisha Brown had to high resolution 3-D motion-capture strongly contrasts the approach of Troika Ranch who build systems they can take on the road and set up quickly in different spaces. There is a good chance that the full version of 'How long does the subject…' with agents and dancers, both performing in real-time, may never be seen again due to the expenses and other complications associated with its production.[37] However, the creation of this work gave Downie the opportunity to advance his thinking on mapping alternatives and agent-based aesthetics, which includes a vocabulary rich in psychophysical metaphor. This we see as making an important contribution to the field alongside Troika Ranch's dedication and resourcefulness.

Both Rémy Muller and Marc Downie described finding ways to grasp and engage with the dance creation process, and both were working with tools they could adjust and tune in ways that did not restrict this.[38] Conditions that allow for 'shared enthusiasm' (Downie) frame the engaged state of mind that makes working together possible. A shared enthusiasm has immediate affect, implies excitement and curiosity, and when it includes 'naming' things together, the overall notion of a shared understanding comes into view. However, it is important to note that sometimes understanding takes place in silence; no verbal descriptions were necessary when Trisha Brown could simply watch the Triangle in action. Crucially however, having enough time and space is a primary ingredient for choreographic computation projects to take advantage of 'shared enthusiasms'. Despite having generous support for their project, Brown has remarked that she felt that they were 'just scratching the surface'.[39]

It seems that a good aesthetic fit between systems and individuals is also important. The artistic approaches of choreographers Gourfink and Brown resonated with the systems they worked with, and Stoppiello has spent nearly her entire performing career working with the technology Coniglio develops. It is important that the work of the EyesWeb and IRCAM gesture analysis teams maintain strong links to science, so that we can draw on descriptions of movement and gesture from other fields such as psychology and neuroscience, and explore how and where these approaches might influence and interact with artistic work. But for the art, the concept of a clear aesthetic vision that fits whatever knowledge of gesture is manifest in the system(s) being used is critical.

In final summary, it seems not the time to make more observations induced from these specific examples. We hope the meeting and this report will serve to inform the field of a subset of rigorous related practices being undertaken by a relatively small number of individuals. At this stage, it is premature to say that this is a 'fresh territory', but we think there is something in this work of great substance that should be further explored and linked to new directions of thinking in science, philosophy and art.[40] But, this will require more support for interdisciplinary research that emphasises choreographic creation and works together to ensure that the capacity of dance remains undiminished.

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Mark Coniglio and Dawn Stoppiello (New York) are media artist and choreographer and co-directors of Troika Ranch – a dance theatre company that integrates dance, theatre and interactive digital media in their live performance works. Coniglio has focused his career as an artist and computer programmer towards a singular goal: to find ways for the movements and vocalisations of performers to interactively manipulate digital media in a meaningful way. http://www.troikaranch.org/

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Myriam Gourfink (Paris) is a choreographer, whose unique work introduces yoga techniques and computer-choreography to contemporary dance, exploring micro-movements and challenging conventional notions of dance. The performance she creates requires extreme physical control resulting in a strange but boundless beauty. http://www.myriam-gourfink.com

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Figure 1: Triangle – captures and recaptures movement from the stage; extending, distorting and moving its body from stage right to stage left (Images courtesy Marc Downie).

Figure 2: Sample screen from the written score for 'This is My House' (Courtesy: Myriam Gourfink).
Figure 3: 'This is My House'. The screens are visible above the dancers (Photo: Rémy Muller).
Figure 4: Screenshot of the EyesWeb 12-pt skeleton (Courtesy: Marc Coniglio).
Figure 5: Lucia Tong in Troika Ranch's 16 [R]evolutions (Photo: Richard Termine).

ENDNOTE: (URLs checked 1 February 2007)

[1]NIME06 workshops: http://www.nime.org/2006/workshops.htm

[2]IRCAM: http://www.ircam.fr/

[3]Real-Time Musical Interactions: http://www.ircam.fr/imtr.html?&L=1

[4]The emerging network comprised at the time: Eyesweb (Genoa); IRCAM (Paris); Animax Multimedia Theater (Bonn); SYMON, University of Birmingham (UK); Monaco Dance Forum (Monaco). See: Scott deLahunta, 'Sharing Questions of Movement', in: Maaike Bleeker, Lucia van Heeteren, Chiel Kattenbelt and Kees Vuyk (eds.), *De theatermaker als onderzoeker: Theater Topics II*, Amsterdam: Amsterdam University Press, 2006, pp. 182–186.

[5]EyesWeb Week: http://www.infomus.org/EYWweek2006/Index.html

[6]See brief biographies

[7]Audio documentation of the presentations available here without the visuals: http://www.du.ahk.nl/forfred/

[8]Le Vasseur, P, 'Computer Dance: The Role of the Computer', *Impulse: The Annual of Contemporary Dance*, San Francisco, 1965, pp. 25–27; Beaman, Jeanne, 'Computer Dance; Implications of the Dance', *Impulse: The Annual of Contemporary Dance*, San Francisco, 1965, pp. 27–28.

[9]John Lansdown, 'The Computer in Choreography', *Computer: IEEE Computer Society Journal* 1978, 11:8, pp. 19-30. And Computer-Generated Choreography Revisited; John Lansdown, '"Artificial Creativity": an Algorithmic Approach to Art'. A version of this paper was given at the Digital Creativity Conference, Brighton, April 1995. http://www.pixxelpoint.org/2001/article-00.html

[10]Merce Cunningham Website: http://www.merce.org/about_danceforms.html

[11]Sources for Trisha Brown's dance making algorithms: Anne Livet (ed.), *Contemporary Dance: An Anthology*, New York: Abbeville Press, Inc., 1978; *The Postmodern Dance Issue: The Drama Review*, 19: 1, March 1975; For William Forsythe discussing algorithms see: Paul Kaiser. 'Dance Geometry: William Forsythe in dialogue with Paul Kaiser', *On Line, Performance Research*, 4: 2, Summer 1999, pp. 66–69. A version can be found on-line: http://www.openendedgroup.com/ideas/conversations.htm

[12]For example see: Norman Badler's work on Human Modeling and Simulation: http://www.cis.upenn.edu/~badler/

[13]See on-line introductory notes at http://www.cs.cmu.edu/~tom/mlbook.html to Tom Mitchell's *Machine Learning*, McGraw Hill, 1997.

[14]See: http://en.wikipedia.org/wiki/Hidden_Markov_Models

[15]http://shf.ircam.fr/523.html for a general description of the score follower: Example paper: D. Schwarz, A. Cont, N. Orio, 'Score Following at Ircam', 7th International Conference on Music Information Retrieval (ISMIR), Victoria, 2006.

[16]F. Bevilacqua, R. Muller, 'Gesture follower for performing arts', Proceeding of the Gesture Workshop 2005, Ile de Berder, France.

[17]EyesWeb site: http://www.eyesweb.org/

[18]IST Project TAI-CHI (Tangible Acoustic Interfaces for Computer-Human Interaction), January 2004–December 2006, http://www.taichi.cf.ac.uk/

[19]A. Camurri, B. Mazzarino, G. Volpe, 'Analysis of Expressive Gesture: The EyesWeb Expressive Gesture Processing Library', in A. Camurri and G. Volpe (eds.), *Gesture-Based Communication in Human-Computer Interaction*, LNAI 2915, Springer Verlag, 2004. For those interested to understand more about low and high parameters, they are described in relation to Digital Signal Processing here: http://www.create.ucsb.edu/~xavier/Thesis/html/node161.html

[20]EyesWeb website/publications list for references to this work. http://www.eyesweb.org

[21]For more information about see: Vera Maletic, *Body-Space-Expression: The Development of Rudolf Laban's Concepts*, Berlin/New York: Mouton de Gruyter, 1987.

[22]For a list of analysis modules see: http://www.infomus.dist.unige.it/EyesWeb/EywMotionAnalysis.html. Upcoming version: EyesWeb XMI with extended multimodal interaction is now under testing.

[23]For an extensive discussion of his agents, see Marc Downie's Doctoral Thesis, 'Choreographing the Extended Agent', MIT Media Lab, September 2005. Available on-line at: http://www.openendedgroup.com/ideas/ideas.htm.

[24]See the 'Artistic Statement' here: http://www.openendedgroup.com/artworks/howlong/howlong.htm

[25]For previous work of these artists, see the website for the Open Ended Group here: http://www.openendedgroup.com/

[26]In the performance of the motion-capture version of Loops, the pre-recorded material is cast into a 'colony' of artificial intelligence agents whose computational responses are visualised in a moving graphic score that never repeats. For more details and also references for these quotes see the reference materials here: http://www.openendedgroup.com/artworks/loops/loops.htm

[27]This project was organised and produced under the title of the 'motion-e project' by the Arts, Media and Engineering program at Arizona State University. Choreographer Bill T. Jones was also involved. Extensive documentation is available here: http://ame.asu.edu/motione/

[28]Example reference for 'mapping' see: Marcelo M. Wanderley (guest editor), 'Mapping Strategies in Real-time Computer Music', *Organised Sound*, 7: 2, 2002. While referencing the increase in 'smarter mapping', e.g. using advanced computation such as machine learning previously mentioned by Bevilacqua, as a good trend, he still questions the use of the term mapping at all' and offers the concept of agent-based aesthetics as an alternative. See his Doctoral Thesis page 39.

[29]Performing Arts Research Team: http://www.ircam.fr/301.html?L=1

[30]Muller's Blog on the theme of 'This is my House' under 'artistic collaborations': http://recherche.ircam.fr/equipes/temps-reel/movement/muller/

[31]The discussion of the meaning of 'agents' is as open-ended as the debate about interactivity; it relies very much on the specific context of its use.

[32]Scott deLahunta, 'Isadora: An interview with artist/ programmer Mark Coniglio', *International Journal of Performance and Digital Media*, 1: 1, pp. 31–46. An earlier on-line version is here: http://www.sdela.dds.nl/sfd/isadora.html

[33]Find quote on the website for the Digital Fellows Program 2003: http://www.dtw.org/dig_fellows03.cfm

[34]For Coniglio's explanation see: http://www.troikaranch.org/16revs/technology.html

[35]Segmentation is widely used in the fields of movement research; breaking a dance phrase or gesture into smaller parts in order to learn something about the whole is often the first step in analysis. Scott deLahunta and Phil Barnard, 'What's in a Phrase?', in Johannes Birringer and Josephine Fenger (eds.), *Tanz im Kopf/Dance and Cognition*, *Jahrbuch der Gesellschaft für Tanzforschung 15*, Münster: LIT Verlag, 2005, pp. 253–266.

[36]Klee, Paul, *Pedagogical Sketchbook*, England: Faber and Faber Limited, 1953.

[37]The final performance may have taken place in the context of the Monaco Dance Forum, 13 December 2006. http://www.monacodanceforum.com/

[38]For a discussion of tuning interactive systems see references to the work of composers and instrument builders Dan Trueman and Curtis Bahn, in S. deLahunta. 'Permuting Connections: Software for Dancers', in Paul D. Miller (ed.), *Sound Unbound: An Anthology of Writings on Sound Art and Multi-Media*, Cambridge: MIT Press, (upcoming 2007).

[39]Quote from Artist's Discussion, Monaco Dance Forum, 14 December 2006.

[40]Erin Manning, 'Prosthetics Making Sense: Dancing the Technogenetic Body', *Fibreculture: The Journal Of Internet Theory and Criticism and Research*, Issue 9 (general issue), 2006 http://journal.fibreculture.org/issue9/index.html