Connecting the Dots:
The dissection of a live optical motion capture animation dance performance

Luc Vanier   Hank Kaczmarski   Lance Chong
Bradford Blackburn   Michael Williams   Anne de Velder.

Materials

Bob's Palace is a multi-media dance piece for nine dancers, one video operator, two camera technicians, one motion capture animation artist/designer and one composer/musician. The subject matter of the dance revolves around panic, anxiety and everyday fears. It premiered at the Krannert Center for the Performing Arts, Urbana, Illinois, on February 4th, 2003.

The equipment used for the performance had two important yet competing requirements. The system had to be mechanically and electrically stable, yet portable, as Bob's Palace was the first dance performed in the three evenings of the University of Illinois' Department of Dance's Festival 2003. Performing first meant we had adequate set-up time but we were only allowed around ten minutes to remove all the gear from above and behind stage in preparation for the next dance.

The system used in *Bob's Palace* starts with a ten digital camera visible red optical motion capture (mocap) system manufactured by Motion Analysis Corporation of Santa Rosa, California (http://www.motionanalysis.com). The camera array is connected to 48 volt DC power and sends capture data to the central computer over a gigabit TCP/IP network switch. The data from the ten cameras are combined to form three dimensional spatial plots of retroreflective markers placed on one or more live performers (one performer in the case of Bob's Palace). This combined (and hopefully stable) dataset is sent over a second gigabit network to a second pc with enhanced memory (1GB) and workstation-class graphics capabilities (3D Labs Wildcat 4210 graphics engine) running a commercial real-time animation program, Filmbox (www.kaydara.com). The high resolution progressive scan computer graphics output from the Filmbox computer is then sent into a Sony DSC-1024HD scan converter which outputs NTSC video compatible with the rest of the system's video capabilities.

As complicated as the mocap system is, it is but one of the video sources which ultimately made it to the rear-projected screen of the dance stage. A Panasonic MX-50 video mixer handled the scan converted mocap image, video from a remote-controlled camera located in the pit aimed at the dancers and video from an off-stage blue chromakey set. An array of monitors, distribution amplifiers and digital and analog video recorders gave the just-off-stage control room the appearance of a network broadcast switching center.

The performance plan was to always use live data from the mocap to drive the animation program in real-time. However, if any of the five billion or so transistors failed in this half million dollar system, a KVM switcher would enable a third computer with a dataset gathered from a previous performance to be substituted for the real-time mocap system.

In the beginning

We started to work on this project during the summer of 2002 when The Beckman Institute's Integrated Systems Laboratory was looking for a dancer to help set up their new infrared motion capture lab. This connection was three years in the making, Hank and Luc having collaborated on two other dance projects.

The first step in this process was to start experimenting with various marker settings. Reflective markers are set on the body so that they can be recognized as triangles by the motion capture software, which then communicates with the animation software that attaches an animated figure (avatar) to the various geometric shapes.

Marker settings were decided upon. Markers are judiciously placed on the body; all markers need to be seen by at least three cameras simultaneously in order to be recognized in space. Triangulation algorithms built into the mocap software require that all ten infrared cameras be placed in a ring above the dancer, viewing as great an area of the stage as possible without sensing the light emitting diode strobe lights of any other camera. Hence, markers that might normally be visible from the stage floor might be occluded by the camera array mounted above the dancers' heads. This limits our possibilities in terms of levels and certain movements. We worked to find the most stable marker setting. It was of primary importance that some markers not be blocked. For example, if the chest and lower back were blocked, the avatar would either distort itself or disappear altogether. This work did not only benefit our dance piece; Yu Hasagawa-Johnson's work, *Hummingbird*, benefited in these experiments (Yu created a cross country internet2-enabled dance (http://www.isl.uiuc.edu/Events/internet_2.htm)). With *Bob's Palace* (which provided our best capture space so far), if as few as two markers were missing for a short period of time, the motion analysis software would stop operating believing that our data was corrupted and that we needed to fix the problem before continuing with the capture.

As this work of setting the markers progressed, we designed a costume/suit for capture. The usual capture suit, made out of a "wetsuit," would be restrictive and not conducive to full movement. We ended up with a unitard, leather shoes, and cap combination that worked well, using Velcro patches sewn into them to attach the markers. An intermediate version caused some problems: the rear zipper and hood bunche up as the dancer looked up. This would invariably falsify the relationship between the markers and at times hide the markers behind a fold of fabric.

Once the marker settings were stable, we started designing various avatars. It is presently very difficult for a moving avatar to look lifelike in real time. In the movie industry, most imperfections are usually corrected during post production. Designing the body involves creating a virtual skeleton. This skeleton does not respond to dance movement in subtle ways. Contractions or undulations of the spine became lost on the avatar, as did stretched knees. Here we are at the mercy of the designers who require certain poses called "Binding poses" in order to align the virtual body to the real one. Often these poses look good as a static drawing but are totally inconsistent with the way a body is normally used. It was often difficult for us to link the two bodies together in a way that was acceptable to a dancer or choreographer. But in trying to do so, Lance came up with our beloved "distorted" avatars. This discovery freed up the movement possibilities as well.

Next, we needed to look at how we were going to use this system on stage. Changing files in Filmbox can be tricky. We decided to restrict the avatars to two files in order to switch only once from one file to the next. This is where the video mixer became useful. It permitted us to create the illusion of using more than two files. Filmbox also provided us with a virtual camera that could be pre-programmed ahead of time, moved around live, or attached to a part of the avatar.

Even at its most consistent, the system portrayed an inherent instability. This suggested a sense of fear or panic to the choreographer. Luc started to design the movement in relationship to the various avatars. For example, the chest had to be upright in order for the body to be captured. The laboratory's capture space is fairly small, approximately 5 by 8 feet. This posed strong restriction on the phrasing of the movement even if we were expecting a larger capture space on stage. It turned out that we had to limit the capture space on stage as well so that audience members wearing reflective materials would not distract the system.

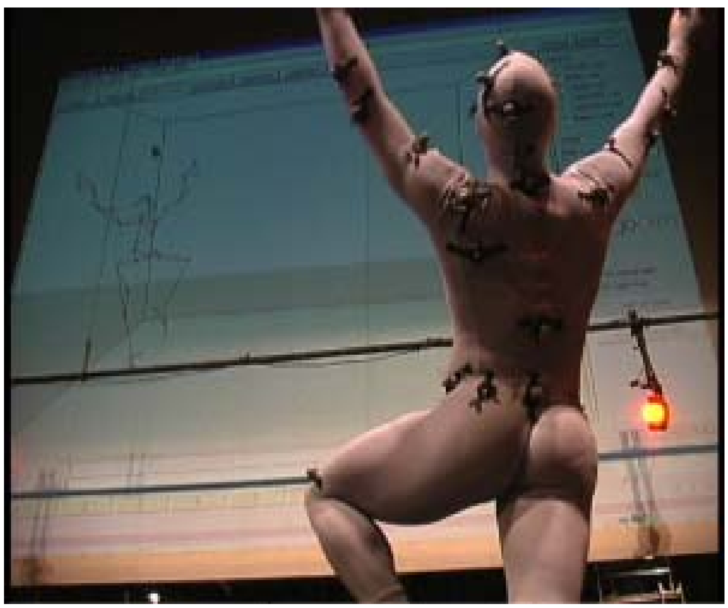
Inside the theater

Given the nature of our project, we did not know what we would face in the theater. The technology worked well inside the solid environment of the laboratory but could it perform as an "island" inside the theater walls? We had to communicate our yet unknown needs to the staff of the Krannert Center for the Performing Arts in order to have a "fly-able" grid built to accommodate the ten cameras. We also needed nine costumes built, including one capture suit and a rehearsal suit for the lab. The shop put together a blue chromakey screen and also helped by lending us a stage light and two strips of marley (dance floor) so, back at the lab we could see if these elements would interfere with the motion capture system.

Two different ideas were bandied around as ways to create a camera array support structure. The first idea, a ring that would need to be dropped down on one end so that it could be raised up after our performance, was discussed but not tried. This solution offered the advantage of locking all the cameras together in an array, but failed to be neighbor-friendly to the existing and additionally required lighting for the other Festival dances. The second idea was ten "spikes" that would lower (like the teeth of a comb) through the "electrics" and hover about twelve feet above the dancers' heads. We tried this approach but rejected it since the spikes could not be locked into a stable realtionship and the cameras had occasional dancing abilities that were interesting, but not appreciated by the mocap software. Both ideas were attempting to create a stable array, meaning that all cameras were locked in relationship to each other inside a structure that would be able to disappear in a few minutes in order to allow the show to go on.

The array had additional requirements: two arms supporting two cameras in the front/center of the array needed to be outside of the lighting grid area (to create additional capture volume) but then retracted (swung in) in order for the array to be flown out. There was also a need for the cameras to be turned off as the red light would interfere with black outs. The third and final idea for the array proved successful. It was a corner-stabilized rectangle with a cross section holding a center pipe span (this proved to be stable enough to do the job). This pipe grid array met the need for rigidity between the various cameras and also supplied the pathway for the cables to reach the two hubs supplying camera power and a one Gig network switch that would then talk to the motion capture computer. The manufacturer's cables made the venture a bit harder than expected; we could not cut wires to fit the array and had to provide an alternative cable pathway for power and network cabling that would rise and lower with the array. Even with our joy at creating a pipe array that locked the camera positions with respect to one another, tying the array to the ground was required to stabilize the array with respect to the stage volume enough for us to get proper capture.

Load in and set up time in the theater took approximately one week after which the mocap computer was still not able to communicate with the Filmbox computer (Filmbox and Motion Analysis software previously were able to communicate with each other through the Beckman's in-house network, a multiple gigabit infrastructure containing virtual subnets, name servers and gateways all unavailable in the ad-hoc network being installed for this performance). Avatar creation proceeded on the Filmbox computer at an off-stage space adjacent to the Playhouse Theater, while we gained an understanding of the software compatibility issues back at the lab. Our set up time every night was consistently close to one hour. That is if all worked well. If someone tripped on the anchoring wires at the last minute, we needed to calibrate the system all over again. Nightly set up required that we refocus the cameras, that we re-calibrate the system, and load the appropriate files. We also needed the capture dancer to come early so that we could make sure the system was "seeing" him correctly once he was in the mocap suit.



We glued Velcro to the markers with J. E. Moser's® Lightning Bond™ High Performance Instant Glue. Later into the performance week, we needed to cut the overhang (the part not attached to the Velcro) off the base on the heel markers because they kept falling off. We also kept adapting the movement so that the dancer's heels would not touch another dancer or the floor. Dance costumes need to be washed; this is why we affixed the markers with Velcro instead of permanently attaching them to the costume. Also, markers can break and, if they do, it is much easier to replace them with a spare marker than trying to attach a new marker on the spot. We needed the fabric to closely follow the movement of the skeleton of the body and not stay in place as the body moved underneath. The back zipper used in the mock capture suit was replaced with openings on both sides of the neck. One of the design difficulties resided in linking the eight other dancers with the dancer wearing the motion capture suit. This was done with color and suggested that the motion capture dancer was going through some kind of transformation that would eventually lead him to be like the others, invisible to the technology.

Various lights interfered with either the projection (we were back projecting on a white cyclorama) or the motion capture system. All normal dance sidelight interfered with the cameras. Lights hitting the floor at a diagonal reflected back into the cameras from the dance floor. We could only use three lighting “looks,” which gave a certain amount of down light as well as a center special, which illuminated the capture space at various times. At some point, we considered putting down a tarp (normally used for operas) as dressing for the stage. We did not think we would need this when our tests in the lab seemed to show that neither the stage lighting nor the cameras' strobe illuminators would reflect on the dance floor. Unfortunately, both lights did, so critical camera look-angle adjustment was used to eliminate this effect, rather than changing the dance floor surface.

The musical score created to underscore the choreography and projected images functioned in three ways: as a live acoustic accompaniment performed by the composer from the back of the stage, as a sequence of prerecorded cues played from the front of the house, and as a real time sonification of the avatar image. This sonification component was realized using a motion tracking/analysis program called Cyclops (written by Eric Singer), which runs with Max/MSP (a graphic object programming language for live electro-acoustic music performance). Cyclops and Max/MSP are both distributed by Cycling’74 (www.cycling74.com). The virtual avatar image was sent from an output of the scan converter to the composer’s laptop. Here the image was analyzed for changes in light differences and motion. The data from this analysis was filtered through a Max algorithm written by the composer to generate musical gestures that responded to the avatar’s movement. The gestures were then sent to a peripheral Yamaha TX81Z FM synthesizer as MIDI control messages, which were then translated into synthesized musical sounds. This interactive component was the central thread that ran throughout the soundscape, in order to unify the disparate musical cues, which accompanied the various vignettes contained in the work. Other musical sources included sound effects from nature that were combined with the harsher sounding electronics as a metaphor for the conflagration of the virtual and human worlds.

In closing

We experienced difficulty in using complex technology outside of a venue for which it was designed. Although site-specific issues were anticipated conceptually, the exact nature of these challenges could only be discovered as the set-up happened. We had adequate time to stabilize the hardware and software in-situ, and modifications to the performance occurred constantly, from small changes that made the animations more understandable to the audience, to changes in the dancers' placement that minimized marker-set occlusion. The light reflecting motion capture system used for Kinesiology experiments and controlled-lighting studio animation work is too environmentally demanding for dance performance, where traditional stage lighting and freedom of movement on stage is desirable. Trade-offs in lighting, image projection, and multi-dancer marker occlusion place constraints on the look of the performance that would not be necessary if the mocap beast were tame. Difficulty in using the system outside of a powerful extant network creates significant hardware and software issues that are beyond the scope of staff at a performing arts center. Lighting grids are not designed to provide the millimeter mechanical stability necessary for consistently stable data sent from the mocap cameras to the computer network.

The multi-dimensionality of the project permits all aspects of art and technology to come together and shares the various areas of expertise of the staff at the Beckman Institute, Krannert Center for the Performing Arts, and the Dance Department that would not have been available in the past: costumes, flooring for dance, understanding the body in movement, etc. We used our resources fully. This sharing made possible a project that would have been unlikely without it. The cost alone would stop most dance departments from getting involved in this kind of technology right now, even before considering the complex infrastructure and knowledge needed to operate the system. In the future, a performance designed optical retroreflective motion sensing system or possibly even a camera-based vision recognition system (not needing markers) might be more readily available to the dance world. Until that time, collaboration is the only way.