# Blending Art and Science in the Production *Collapse (suddenly falling down)*

Michael Neff (computer scientist, educator) 1 Shields Ave., Davis, CA 95616, neff@cs.ucdavis.edu

Dawn Sumner (geologist, educator) 1 Shields Ave., Davis, CA 95616, dysumner@ ucdavis.edu

Gerald W. Bawden (geologist) U.S. Geological Survey, Water Resources Division 6000 J Street, Placer Hall, Sacramento, CA 95819, gbawden@usgs.gov

Ellen Bromberg (media artist, choreographer, educator) 330 S 1500 E, Salt Lake City, UT, 84112, e.bromberg@utah.edu

James P. Crutchfield (physicist, educator) 1 Shields Ave., Davis, CA 95616, chaos@cse.ucdavis.edu

Della Davidson (interdisciplinary theater artist, choreographer and educator) 1 Shields Ave., Davis, CA 95616, della.davidson@mindspring.com

Shelly Gilbride (performance studies scholar) 1 Shields Ave., Davis, CA 95616, esgilbride@ucdavis.edu

Louise H. Kellogg (geophysicist, educator) 1 Shields Ave., Davis, CA 95616, kellogg@ucdavis.edu

Oliver Kreylos (computer scientist)1 Shields Ave., Davis, CA 95616, kreylos@cs.ucdavis.edu

Abstract:
*Collapse (suddenly falling down)* was a dance/theater/media production that brought together a diverse group of artists and scientists to explore the varied ways that social and natural systems collapse and the response of human societies. This paper focuses on the nature of the collaboration, the unique products it produced, and the lessons learned. Three art-science collaboration themes emerged: 1) implementation of a large-scale stereo display for 3D data; 2) exploration from a visual design perspective of digital scans of natural hazard sites normally used for scientific research; and 3) integration of optical tracking for interaction between performers and visualizations. Each theme is explored in detail and each member of the team reflects on lessons learned from the process.

Art-science collaborations require blending the artistic, quantitative, and technical sensibilities of people from different professional and cultural contexts [1]. We explored different approaches to understanding the collapse of systems through a collaboration among performing artists and earth, physical, and computer scientists. The collaboration initiated with extended discussions among friends and colleagues about how artistic exploration could enhance scientific interpretations of data. It became focused on artistic performance when a piece was commissioned for Davidson, choreographer. The vision for the piece centered on exploring interactions among people and their environment when social and natural systems collapse. Here, we describe the components of the production, *Collapse (suddenly falling down)* [2], that emerged from artists and scientists working closely together, including 3D projection of scientific data with motion capture-based interaction [3]. Our focus in this paper is on the nature of the collaboration, the products it produced, and the lessons that emerged from that collaboration.

## Origin of *Collapse (suddenly falling down)*

The Robert and Magrit Mondavi Center for the Performing Arts commissioned a piece for the ***Sideshow Physical Theatre***, the resident professional company of the Mondavi Center and the Department of Theatre and Dance at UC Davis. For this commission, director and choreographer Davidson wanted to explore relationships among people, societies, and nature when systems collapse and recover. Many natural systems respond to human use in ways that feed back to society, often with dramatic and unanticipated consequences [4]. These instabilities can be explored scientifically in studies of natural hazards, as well as the physics of nonlinear systems [5]. Based on discussions with scientists Sumner, Kellogg, and Crutchfield, Davidson incorporated scientific data visualization techniques into the performance to deepen insights into how people interact with collapsing systems.

3D interactive visualization of scientific data has been a major research focus for computer scientist Kreylos, geoscientists Sumner and Kellogg, and physicist Crutchfield, all collaborators in the Keck Center for Active Visualization in Earth Sciences (KeckCAVES) [6]. *Collapse* provided an opportunity to explore the potential and limits of these visualization techniques by presenting them to large audiences to achieve the nonscientific (artistic) goals of the performance. Real-time interaction with data is an important component of the work in the KeckCAVES, and the scientists wanted to extend this to the performance setting. This led to an invitation to Neff to join the collaboration to provide motion capture expertise for real-time interaction in a theatre space.

The broad scope of research in the KeckCAVES meant that a wide range of data were available. Our first major decision, choosing what type of data to use, revealed potential pitfalls and provided a template for our collaborative process. The choice of data determined the artistic and technological parameters of the work, and at each stage we were at risk of providing too many options for too long. Digital media artist Bromberg joined the collaboration to provide a strong artistic vision on how to use 3D data effectively in a live theater-dance performance. After exploring different data types and visualization methods with the scientists, Davidson and Bromberg chose Tripod-Light Detection and Ranging (T-LiDAR) data (Figure 1). These scans were selected for their visual and metaphoric qualities. T-LiDAR is a ground-based laser ranging system that sends out millions of laser pulses and records their reflections, generating a threedimensional pointilist image of the scanned landscape [7]. The best datasets for *Collapse* were collected for scientific study of natural hazards such as landslides by geophysicist Bawden, who joined the collaboration and made data available for performance.

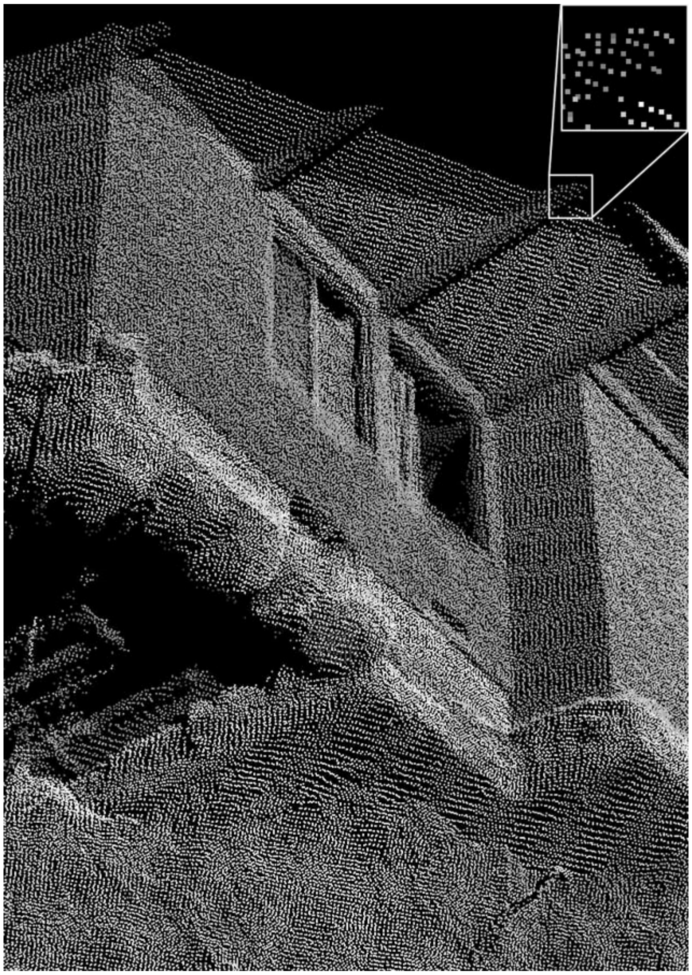

**Figure 1: A T-LiDAR scan looking up through the floorboards of a house after a landslide removed part of its foundation. The inset shows a close-up of the placard-based visualization, revealing gaps between reflections.**

The art-science collaboration thus self-assembled around a shared vision of exploring complex natural, engineered, and social systems and a shared interest in using technology to address both scientific and artistic questions. The contributors were dedicated to fully integrating the scientific visualizations into the performance, both thematically and aesthetically, and shared the desire to explore fundamental behaviors of complex systems in artistically meaningful ways.

As director and choreographer, Davidson provided the overall vision for *Collapse,* guiding the thematic framework. She allowed choreographic, dramatic, set, music, and data visualization elements to develop independently, each with an individual or subgroup responsible for exploring the theme within a given medium (Table 1). This autonomy and responsibility promoted full involvement of diverse people in the collaboration, allowing individual contributions to substantially impact the final performance. Davidson trusted each subgroup to provide relevant material, including a pre-show piece that coupled visual representations of chaotic attractors and sound [8]. Integration of the separate components into a cohesive whole took place during 10 days of technical rehearsals leading up to performance.

Several recent works incorporate geoscience data into dance performances [9]. In addition, a large body of work explores dance and technology, including Cunningham's influential *BIPED* [10]. *Collapse* incorporated visualization of geoscience data, motion capture, and interactive technology, and explored the interactions between society and the natural world, both through choreography and acting, and by using data collected for scientific study and mitigation of natural hazards. As a result of its success, *Collapse* was honored with the 2009 Isadora Duncan Award for Visual Design. In preparing *Collapse*, three art-science collaboration themes emerged: 1) implementation of a large-scale display for 3D data; 2) exploration of natural hazard T-LiDAR data sets from a visual design perspective; and 3) integration of optical tracking for interaction between performers and visualizations [11]. Each theme is explored here by presenting technical details of the performance and reflections on the collaboration process.

## Staging

Five dancers and three actors (Table 1) contributed to a loose and epdisodic narrative that provided the throughline of the performance, following the last two inhabitants of Easter Island as they argue about cutting down the island's last tree. When an anthropologist arrives on the island to study the islanders, the narrative deepens to explore the limitations of language, globalization, genocide and survival. The narrative is interwoven with dance sequences and the visual imagery of the T-LiDAR data, providing audiences multiple visual and expressive perspectives on the nature of collapses.

The highly dynamic set featured a suspended tree that slid across the stage from a rail (Figure 2). An island of three sod-covered platforms was wheeled around the stage by the performers, coming together and breaking apart to evoke earthquakes and disappearing pastoral lands (Figure 3). The rear of the set incorporated a polarization-preserving 16' x 9' projection screen for 3D images and stacks of two foot square white boxes (Figure 4). T-LiDAR scenes were projected across the entire stage, in stereo on the screen. An optical motion capture system allowed manipulation of the data by performers. At cued intervals, columns of boxes came crashing down towards the audience, revealing metal scaffolding that served as another performance space. At times, visual elements, coupled with frenetic choreography and fragmented narrative, invoked the chaos of systemic collapse. At other timess, ethereal T-LiDAR scenes and tender dance duets created a sense of calm in the aftermath of collapse, evoking opportunity, hope, and resiliency.

**Figure 2: Actors Orzechowicz and Zimmerman interact with a movable suspended tree. (Photo © Luiza Silva)**

**Figure 3: Performers reposition the three-piece island stage. T-LiDAR imagery fills the background. The 16' x 9' polarization-preserving projection screen is in the upper left-hand corner. The projection continues onto the stacks of boxes on the right and onto the floor. (Photo © M. Neff)**

**Figure 4: Dancers Marling, Mehling and Terrell-Carazo perform in front of T-LiDAR projections. (still from video)**

The complexity arising from the varied elements provided both artistic and technical challenges. It was important to offer the audience a multisensory experience that did not overwhelm viewers with visual cacophony. Appropriate changes in pace ensured that all elements built on each other. Moments focused on individual elements enabled the audience to become familiar with that component. As the performance progressed, overlapping elements highlighted the chaos and confusion during collapse of a system.

### *Theater-Scale Display of 3D Data*

*Collapse* required projection of 3D data to a large audience, so two high power projectors, polarizing filters, and a 16' x 9' polarization preserving screen were installed. The audience was provided with inexpensive polarized glasses which provided minimal visual interference when viewing the rest of the show and could be worn or not according to personal preference. Computers controlled data projections and optical motion capture equipment, and enabled coordination with theater cues. T-LiDAR projection software [12] and optical motion tracking software [13] were available prior to *Collapse*. However, software linking projections to optical tracking and allowing cued coordination was developed by Kreylos for the performance. A set of trackable input gestures was defined by Neff, Davidson, Bromberg and Kreylos working with the performers. All technology, projection equipment, and the time of the scientists and software engineers were provided at no cost to the performance; we note that these may not be available to many artists and so access to technology may generally inhibit arts-science collaborations of this type.

Projecting 3D data in the performance space required careful consideration of the audience's viewing experience. Rendering requires a fixed viewpoint, and large screens can produce parallax problems for audience members at the edges of the space. To counteract this, the screen was significantly smaller than the stage. However, to fill the audience's visual field with T-LiDAR images, 3D visuals were projected across the back wall and floor, so that the moving images extended across 60’ x 20’ (Figure 4 and videos [14]).

During performance, T-LiDAR scenes were rendered in real time. Although the audience could not distinguish between real-time and pre-recorded renderings, real-time rendering was required for interaction, and to allow the artistic team to adjust and set projection elements during rehearsals in response to other evolving performance elements. *Collapse* benefited from real-time data exploration capabilities while promoting their further development; a scientistific goal is to provide real-time rendering in diverse environments, and the performance offered a testbed for a large audience installation.

### *T-LiDAR Projections*

The imagery for *Collapse* focused on T-LiDAR data, which consists of points representing laser reflections exactly located in 3D space. Each reflection is represented by a small square placard (Figure 1). The T-LiDAR scenes used for *Collapse* consist of up to hundreds of millions of points. When objects are viewed from a distance, they appear solid because the placards overlap, but when viewed closer, gaps between placards become visible, and the image appears to break apart. Foreground objects such as trees cast shadows onto more distant objects, creating holes in the scene. The net result is images with a ghost-like, pointilist appearance.

Scenes related to the collapse of natural systems were chosen by Bromberg, Bawden, and Kellogg. They included: 1) the 2005 Laguna Beach, CA landslide showing broken and precarious houses (Figure 1); 2) an Oklahoma environmental disaster area where lead and zinc were mined for bullets throughout the 20th century; 3) a canyon in California created by debris flow following a wildfire that filled homes with rocks and mud; 4) beach erosion on Waikiki Beach, HI that threatens the state’s economy (Figure 5); and 5) the failed Ka Loko Reservoir dam on Kauai, HI. Scenes were chosen for their visual impact and to show the impact of environmental changes on communities.

**Figure 5: Dancer Chen uses reflective markers attached to her hands in order to spin a T-LiDAR scan of woman on Waikiki Beach, shown on the back wall. (Photo © M. Neff)**

T-LiDAR scenes are difficult to appreciate as still images, but are visually compelling when moving, especially when rendered in 3D. To ensure that key elements in the scenes were effectively displayed, Bromberg, Kellogg, Kreylos, and Bawden choreographed "fly-throughs" of the scenes, with perspectives and pacing chosen to invite comparisons among objects or reflection on the theme of collapse. The viewpoints and paths were thematically tied to the choreography and acting. Several paths focused on individual trees in different environments, as trees were a recurring motif in *Collapse*.

To enable fly-through scripting, Kreylos wrote software allowing a virtual camera to be manipulated to select specific views within the data. Natural splines were used to smooth the transitions between views. These splines provide motion with no discontinuities in acceleration, resulting in a desired organic feel, but require significant editing. Paths were initially chosen within the KeckCAVES immersive environment, a 10'x10'x8' virtual reality space, but when they were projected in the theater, the point-of-view shifted, substantially changing the visual effect and requiring refinement of each path. Development of the necessary software, setting views, and fine-tuning fly-throughs continued throughout technical rehearsals. This effort was well spent. The fly-throughs so effectively communicated story lines and themes that they became a significant performance element.

### *Interaction*

Research in the KeckCAVES enables real-time interaction of scientists with their data to produce insights that are not available with delayed rendering tools. A high priority for the scientific collaborators was the integration of interaction into *Collapse*. However, the artists and performers had no prior experience with the technology, and lack of access to an interactive system during early rehearsals inhibited full development of real-time interaction in performance. This was the most significant challenge of the collaboration, and we view this as an important future avenue for development. However, we successfully used interaction to provide a tangible connection between the dancers and the projections in two scenes.

The interaction system consisted of an optical tracking system that provided 3D marker locations to the visualization software. Neff provided motion capture with a 12 camera Vicon MX 40+ system [15], with five cameras mounted 15' high on each side of the stage and two cameras mounted behind the audience. The moveable tree was positioned to minimize occlusions during interactive scenes. Due to reflections from the light grey Marley floor, certain light cues could not be used simultaneously with motion capture. The style of dance was athletic and aggressive, so markers needed to be easily attached and removed. A simple elastic harnesses that slid over a performer's hand was designed for this purpose. Overall, the camera layout, lighting and stage design, and choice of 25mm markers yielded a very reliable, 20'x25'x10' capture volume.

The piece featured two forms of interaction: real-time manipulation of T-LiDAR data; and free-form drawing. The interaction vocabulary for data manipulation used two markers. Moving the markers in unison panned the projected image. Moving them closer together or farther apart zoomed the image in or out. Revolving the markers around each other created a corresponding rotation. Interaction began when the markers were revealed by opening a hand with an attached marker and stopped when the markers were covered. Dancer Chen manipulated a T-LiDAR scan of Waikiki beach that featured an isolated woman standing in the water (Figure 5). Only the front of the woman had been scanned, so she appeared as the ghost-like half of a person. In this scene, Chen walked onto the stage, opened her hands to reveal two markers, and then slowly manipulated the scene with her hands to demonstrate the connection between her motion and the projected display [16]. Slowly, meditatively, she rotated the scene back and forth, around a fixed axis of rotation that passed through the woman in the water. Chen gradually increased the speed of her rotations, building into a rapid Dervish dance, eventually collapsing to the floor. As she spun, the projected world behind her also spun, rapidly rotating around the image of the woman in the sea. Once Chen collapsed, she covered the markers, terminating the interaction. The image lingered at whatever spot the tracking system lost view of the markers, and then slowly drifted downward out of view.

The second interaction embedded a moment of calm in the high energy production. A single dancer, Marling, moved a marker through space, drawing a house and tree on the screen as his hand acted like a brush (Figure 6). The images were created using a cloud of virtual particles that expanded and slowly faded as he drew; by the time the tree was finished, the house had disappeared [17]. This scene tied the visual display to the tree on stage and trees referred to in the text. Freeform drawing arose directly from participation of scientists in technical rehearsals. Kreylos wrote an application to test the integration of motion capture with the visualization software during long hours in the control booth, and as Marlin experimented with the new application, Davidson saw its potential and included this new element in the performance.

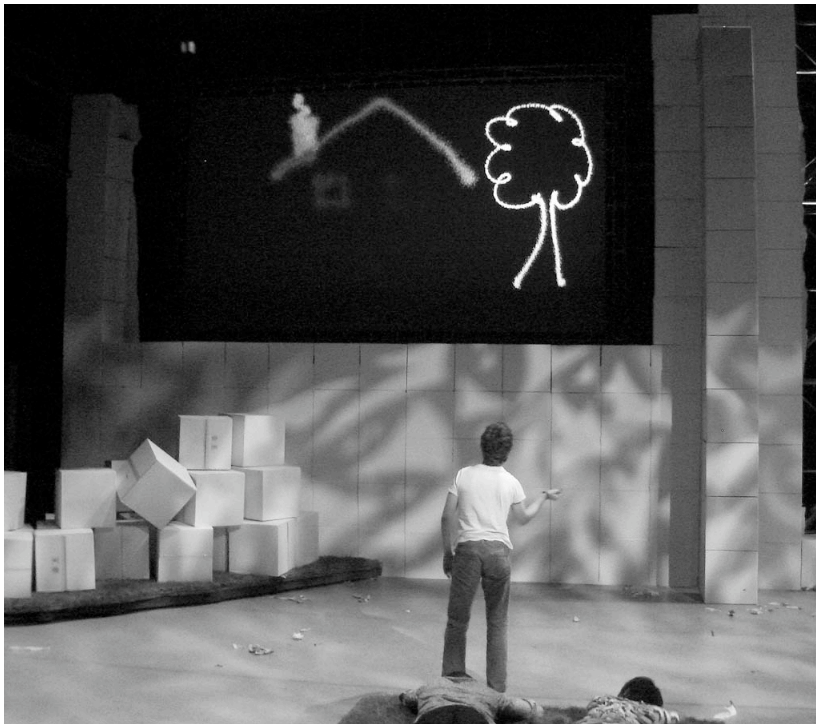

**Figure 6: Dancer Marling uses 3D interaction to draw a house and tree on the screen at the back of the stage. (Photo © M. Neff)**

While interaction contributed significantly to the performance, our experience suggests that full access to a visualization and interaction system is needed throughout rehearsals. Performers require time both to learn to dance while interacting with digital projections and to improvise with the technology to explore how it can be used expressively. The power of interaction became quickly apparent during technical rehearsals. However, data manipulation required so much attention that performers felt limited while controling the visualizations. Time for interaction during rehearsals is vital for the artists to determine how to use this medium. Thus, early establishment of both the visual vocabulary and interaction techniques will expand the potential of interactions in future collaborations.

## Reflections on the Performance and Collaboration

*Collapse* was a complex show, and bringing the many diverse elements together during technical rehearsals was challenging. The technology needed to be integrated and tested in the space and the performers needed to rehearse with the set, all within limited hours in the theater. All elements continued to evolve during technical rehearsals, and the needs of various groups were not always well understood by the others. Good communication, curiosity, and an overriding spirit of cooperation founded on a deep respect for each other were key to success.

Despite the challenges, the many elements merged to offer a powerful reflection on collapse in its diverse forms. Scientific contributions supported the artistic vision without dominating the performance, contributing additional meaning and inviting the audience into the world of the stage in new ways. Audience response was positive. More than 900 people saw the production, and after one performance, more than 50 people participated in a lively post-performance discussion. The integration of science imagery and dance led to diverse responses from the audience, demonstrating that they were intellectually challenged and that the show inspired them to think about beauty in science and intellectual inquiry in dance. Many perceived the images differently as the work progressed, gleaning more meaning through time. For example, some initially thought that the images were abstract paintings; after images shifted in perspective, they realized that they were viewing real-world landscapes. This developing revelation provided a deeper context for contemplating collapse, meeting the artistic intent of the piece.

Another measure of success for an art-science collaboration is the effect of shared efforts on each participant. For some, this was our first significant art-science collaboration whereas others typically work at the boundary between art and science. All will continue as part of the collaboration to restage *Collapse* and for other projects because we value the newly developed perspectives on our individual research and interests. We end with brief reflections on what this collaboration brought to us individually.

**Bawden** (Geophysicist): I benefited from the technological advances developed for *Collapse* in my daily scientific analysis of disasters and in presenting the imagery to both scientific and public audiences. In Spring 2008, I used the *Collapse* 3D projections system in my California State University Sacramento Science Technology Engineering, and Mathmatics keynote lecture reaching an audience of ~400. The technology made it possible to illustrate complex concepts in 3D with the data literally projected over the audience. *Collapse* also changed how I collect T-LiDAR data for scientific analysis; I now look at landscapes through artistic eyes with attention to the natural detail and beauty, visualizing how it can be expressed in future collaborations.

**Bromberg** (Media Designer): The making of *Collapse* was an exciting collaboration in which each participant brought tremendous expertise to a common purpose. From a meta and perhaps lofty perspective, the capacity to join through our differences, trust in our individual contributions, allow for chaos, and find solutions, exemplifies what we are capable of as human beings. And through this engagement, we have the potential to grow as individuals and as communities. I believe this was truly what happened in the *Collapse* collaboration. We created a community of inquiry, in which our individual perspectives were enhanced, by seeing through the eyes of others. From a personal artistic perspective, I have been exploring interactivity and representation of space in my stage, video and technology projects. The opportunity to work within truly 3D virtual environment was a tremendous experience.

**Crutchfield** (Physicist): The intuitions driving *Collapse* still surprise me. During the half-year preceding the performance in Fall 2007, there were only the barest hints of the impending world-wide failure of market systems. Though aware of long-term shifts in climate dynamics, in our early discussions we, like so many others, could not have guessed what would soon quickly follow. Working on *Collapse* heightened my sensitivity to unfolding and surprising news; my background in nonlinear physics suggested the wild variations were a harbinger of systemic change. When all is said and done, I ended up seeing *Collapse* as an aesthetic outlet to a rational discomfort. Much like horses purportedly running awry before an impending quake, the causal link is unclear, but *Collapse* expressed a moment of collective attention.

**Davidson** (Choreographer): Creating a performance piece is the exciting process of gathering a community of multiple creative minds working simultaneously to explore an idea. With *Collapse,* it was a community of scientists and artists responding to each other's specific knowledge to create a world on stage unique to itself, a world greater than the sum of its parts. Jon Rossini, the dramaturge for the project, stated, "the multiple interesting aggregation of rich moments and textures occupy the space, building upon each other, asking each of you to think about the ideas of collapse." This collaboration broadened my understanding of the potential for creative partnerships between artists and scientists and, in extension, the possibilities for the stage.

**Gilbride** (Performance Scholar): This project invigorated my interest in interdisciplinary collaboration as a way to explore new creative possibilities on the dance stage and beyond. It was interesting to watch experts in disparate disciplines with very different methods of intellectual exploration find common language for a shared creative goal. This collaboration inspired me to think about creativity beyond the arts and explore creative engagement as knowledge production. Observing the process also challenged me to think about interdisciplinary communication and boundaries that inhibit or enhance creative processes and innovation. I was astonished by the shared intellectual excitement between the artists and scientists and the level of commitment to crafting a cohesive, intricate artwork as a mode of research and exploration.

**Kellogg** (Geophysicist): Working with scientific data in the context of the performance was enlightening. Faced with an image of a natural disaster site, we, as humans, seek understanding of events that led to collapse, but our pursuit of insight leads scientists and artists in very different directions. I have continued to use choreographed fly-throughs in my own work, particularly in presenting to scientific audiences. This element of *Collapse* has taken on a life and presence of its own, and the arts-science-technology collaboration has motivated some new directions for both technical development and scientific discovery.

**Kreylos** (Computer Scientist): The collaboration to produce *Collapse* was a substantial challenge from the software perspective. On the one hand, we had to make substantial additions to our existing software to provide the functionality required for the performance. This was especially challenging because those requirements changed in response to the evolving artistic vision during technical rehearsals. On the other hand, it was very stressful having to rely on prototype software that was not designed for the robustness required by performance applications.

**Neff** (Computer Scientist): Working on *Collapse* reinforced my belief in the importance of developing computer tools that support spontaneity and allow direct artistic exploration through play. I am interested in future collaborations in which interaction is incorporated early in rehearsals, allowing images and interactions to be developed in synchrony as performers work on the other core ideas of the piece. The collaboration has motivated my work on a new set of software tools for visual performance.

**Sumner** (Geologist): The *Collapse* collaboration expanded my view of my own data, even though these data were not integrated into performance. I gained a new appreciation of the importance of viewpoint and motion for understanding spatial relationships, and perspective and communication for personal relationships. The collaboration led to a desire to present scientific ideas in new ways and with interactions designed by artists. Integrating artistic sensitiblities into scientific data interpretations and presentations provides deeper insights on many levels.

## References and Notes

[1] **Beyond Productivity: Information, Technology, Innovation, and Creativity**, Committee on Information Technology and Creativity, Computer Science and Telecommunications Board, National Research Council, W. J. Mitchell, A. S. Inouye, and M. S. Blumenthal, editors, The National Academies Press, Washington, DC (2003). V. B. Mansilla and D. Dillon and K. Middlebrooks, "Building Bridges Across Disciplines: Organizational and Individual Qualities of Exemplary Interdisciplinary Work", Issues in Interdisciplinary Studies **24** (2004) 1-31.

[2] Davidson, D, "COLLAPSE, Suddenly Falling Down", Sideshow Physical Theater at Mondavi Performing Arts Center, Oct. 25 – Nov. 4, 2007.

[3] Neff, Michael, Dawn Y. Sumner, Gerald W. Bawden, Ellen Bromberg, Della Davidson, Shelly Gilbride, Louise H. Kellogg, and Oliver Kreylos, 2009, Blending art and science to create *Collapse (suddenly falling down).* Leonardo Transactions http://www.leonardo-transactions.com/announcements/.

[4] Diamond, J. 2005, *Collapse: How Societies Choose to Fail or Succeed,* Viking Penguin, London.

[5] See for example: http://www.usgs.gov/hazards/. D. Sornette, **Why Stock Markets Crash: Critical Events in Complex Financial Systems**, Princeton University Press, Princeton, New Jersey (2004).

[6] See http://keckcaves.org for more information.

[7] Cracknell, Arthur P. and Ladson Hayes, 2006, **Introduction to Remote Sensing,** Taylor & Francis, London, 352 pp.

[8] Crutchfield, James P., David D. Dunn, and Ed Puckett, 2009, Chaos All the Way Down—Pre-show to Collapse (Suddenly Falling Down), Leonardo Transactions http://www.leonardo-transactions.com/announcements/.

[9] "Ballet Mori" a solo performed by Muriel Maffre (San Francisco Ballet at SF Opera House, April 2006), using K. Goldberg's soundtrack derived from real-time seismological data; "The Mountain", a CityDance Ensemble-DANTE collaboration set to a sound track derived from volcanic seismic activity, choreographed by Jason Garcia Ignacio, (http://www.geant2.net/server/show/ConWebDoc.3075).

[10] *BIPED*, Merce Cunningham Dance Company, first performance at Berkeley, California 1999.

[11] James, Jodi; Ingalls, Todd; Qian, Gang; Oldon, Loren; Rikakis, Thanassis. "Lucidity: A Movement-based Interactive Dance Performance." "LEA-ACM Multimedia" Special Issue, Leonardo Electronic Almanac Vol. 15, No. 5 - 6 (2007). 10 May 2007, http://leoalmanac.org/journal/vol_15/lea_v15_n05-06/jjames.asp

[12] Kreylos, O., G. W. Bawden, and L. H. Kellogg, 2008. Immersive Visualization and Analysis of LiDAR Data, in press in Lecture Notes in Computer Science, Special Issue Proceedings of ISVC08.

Kreylos, O., 2008. Environment-Independent VR Development, in press in Lecture Notes in Computer Science, Special Issue Proceedings of ISVC08.

Billen, Magali I., Oliver Kreylos, Bernd Hamann, Margarete Jadamec, Louise H. Kellogg, Oliver Staadt, Dawn Y. Sumner, 2008. A Geoscience Perspective on Immersive 3D Gridded Data Visualization, *Computers and Geosciences*, 34/9 pp 1056-1072.

[13] Vicon.Twelve Vicon MX 40+ cameras were used for motion capture. Input gestures were based on tracking one or two markers whose locations were calculated by Vicon software. A driver passed this information to visualization software. The driver filtered the data stream to accommodate brief marker drop out or the occasional appearance of spurious markers. For technical details on the hardware, see: http://www.vicon.com

[14] Videos of the performance available at http://youtube.com/collapseucd

[15] Vicon

[16] http://youtube.com/collapseucd

[17] Ibid.

[18] Crutchfield, Chaos All the Way Down.

Table 1

| *Collapse (suddenly falling down)* **Personnel** |
|---|
| Directed and Choreographed by Della Davidson |
| In collaboration with and Performed by Jane Schnorrenberg, Kegan Marling, Kerry Mehling, Victoria Terrell-Carazo, Christine Chen, Sara Zimmerman, Victor Toman, and David Orzechowicz |
| Script by Ed Gaible |
| Music by Richard Marriott |
| Lighting Design by David K. H. Elliott |
| Digital Media Design by Ellen Bromberg |
| Costume Design by Rachel Stone |
| Scenic Design by Jennifer Michelson |
| Geoscience Contributions from Dawn Sumner, Louise Kellogg, and Gerald Bawden; Nonlinear Physics Contributions from James Crutchfield |
| T-LiDAR Scans by Gerald Bawden |
| Computer Visualization and Programming by Oliver Kreylos |
| Motion Capture Integration by Michael Neff |
| Pre-Show Installation by James Crutchfield, David Dunn and Ed Puckett [18] |