ARTISTS' ARTICLE

danceroom Spectroscopy

At the Frontiers of Physics, Performance, Interactive Art and Technology

THOMAS MITCHELL, JOSEPH HYDE, PHILIP TEW AND **DAVID R. GLOWACKI**

ABSTRACT

danceroom Spectroscopy is an interactive audiovisual art installation and performance system driven by rigorous algorithms commonly used to simulate and analyze nanoscale atomic dynamics. *danceroom Spectroscopy* interprets humans as "energy landscapes," resulting in an interactive system in which human energy fields are embedded within a simulation of thousands of atoms. Users are able to sculpt the atomic dynamics using their movements and experience their interactions visually and sonically in real time. *danceroom Spectroscopy* has so far been deployed as both an interactive sci-art installation and as the platform for a dance performance called *Hidden Fields.*

Interactive technology is opening up fascinating possibilities across a range of different performance-related areas in the arts, including dance [1] and music [2]. This technology is also opening up innovative approaches for expressing and communicating scientific concepts [3]. While there have been numerous calls for increased dialogue between computer science and the arts [4], and while computer science and interactive technology are frequently combined to deliver interactive artistic content [5], to our knowledge, there are relatively few examples of projects in which interactive technology and computer science provide the interaction site for engagement between arts practice and scientifically rigorous concepts and algorithms.

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Article Frontispiece. Participants use their energy fields to steer the atomic dynamics simulation of the Earth's atmosphere, generating both graphics and sound within a 360° projection dome. (© Interactive Scientific Ltd. Photo: Paul Blakemore.)

As arts practice increasingly comes to utilize and gain familiarity with interactive technology and tools from computer science, it necessarily develops fluency with the algorithmic thinking and language that dominates the discourse, models and analogies used in modern science (e.g. across fields as diverse as physics, biology, nanotechnology, neuroscience, linguistics, economics and sociology) [6]. Consequently, the time for interaction between art and science is ripe, as both increasingly draw from a common foundation in computer science [7].

In this paper, we describe recent progress in the design of a state-of-the-art system that utilizes interactive technology as the creative hub linking artistic practice with rigorous algorithms and research methods commonly employed to understand and simulate nanoscale atomic dynamics in a range of physical systems (e.g. materials science, biophysics and environmental processes). The name of the system is *danceroom Spectroscopy* (*dS*), and it is shown in the Article Frontispiece.

SCIENTIFIC AESTHETICS AND MICROSCOPIC DYNAMISM

Scientists and philosophers of science have long considered the extent to which aesthetics guides the process of scientific discovery [7]. Paul Dirac, the Nobel Prize–winning theoretical physicist, provocatively stated, "It is more important to have beauty in one's equations than to have them fit experiment" [8]. Richard Feynman likewise described science as a means to uncover levels of hidden beauty that exist in dimensions smaller than we can see with our eyes [9].

Technology has extended the abilities of our natural senses, enabling us to see previously invisible phenomena, changing our perceptions and experiences of reality and opening up new domains in aesthetics:

> We are in the territory of aesthetics [and] sensory perception [where] an aesthetics of non-sensory perception is involved, namely the perception of phenomena hitherto inaccessible to natural sensory perception. This is an

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extension of aesthetics: from the perception of visible things with natural organs, to the perception of invisible things with the help of apparatuses [10].

Atoms and molecules are too small for us to see. Their depiction in scientific literature thus reflects the representations that researchers use to understand them [11]. Detailed molecular and atomic visualizations originate not from reality but rather from the imaginations of scientists [12]. As they delve deeper into the atomic world, researchers increasingly rely on imagination and visualization, which has led to interest within the scientific and graphics communities regarding the relationship between aesthetic representation and scientific imagination [13–15]. While intended to convey information and stimulate new understanding, the visualizations that arise from combining aesthetics and science reveal the hidden beauty that is encoded into the mechanics of the natural world [16].

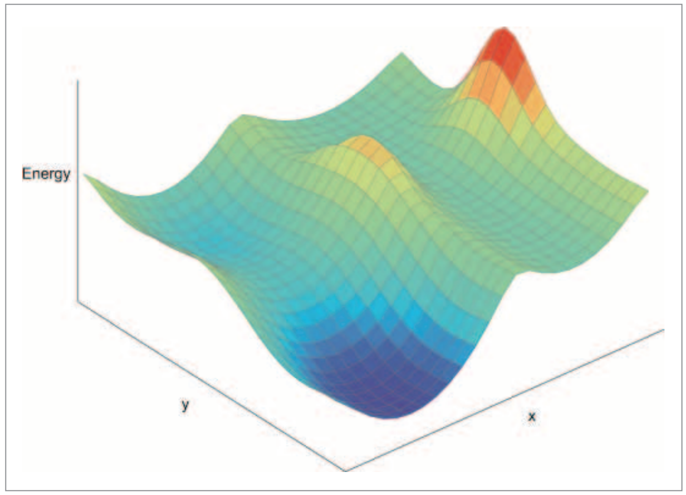

Fig. 1. Two-dimensional generic energy landscape showing energy as a function of two idealized spatial coordinates, *x* and *y*. (© Thomas Mitchell)

The microscopic world is dynamic. In fact, Heisenberg's uncertainty principle, one of the fundamental principles of quantum mechanics, guarantees that everything is characterized by perpetual jiggling and wiggling, with vibrational motion and structural fluctuations that span a range of timescales and corresponding lengthscales. For example, electron dynamics occur on timescales of attoseconds, while vibrations within cells can last for seconds. Microscopic dynamism determines the macroscopic properties of matter and thus shapes our phenomenological experience of nature. However, the dynamism of the atomic world is not so obvious, because "seeing" this behavior requires temporal and spatial resolutions that far exceed the capabilities of our eyes. No doubt it is this gap between scientific observations and our everyday experience that underpins Richard Feynman's famous statement: "It's very hard to imagine all the crazy things that things really are like" [9]. *dS* directly addresses this missing sense of dynamism in our aesthetics of the invisible, showing clearly how invisible forces are linked to microscopic dynamism.

ENERGY LANDSCAPES

In order to understand and predict system dynamics, chemists and physicists frequently invoke the idea of an "energy landscape," which is effectively a topological map of the forces that an atom feels in different molecular configurations. The energy landscape metaphor can be used to rationalize the motion of nearly every class of particle, atom and molecule in the universe. It has consequently become prevalent within the discourses of chemistry, physics and biology [17,18]. Figure 1 shows a simple schematic of a two-dimensional energy landscape, where the energy is a function of arbitrary x and y coordinates. The energy landscape shown in Fig. 1 is simplified in two respects: (1) real energy landscapes generally have a significantly higher dimensionality, since they depend on the interaction between any given particle with every other particle, and (2) real energy landscapes are time dependent, owing to structural fluctuations and external fields.

Despite the simplicity of Fig. 1, the energy landscape metaphor has become fundamental to the way in which the physical sciences rationalize dynamic behavior. To a good approximation, atoms move on energy landscapes in a way that shares similarities with how humans move through physical landscapes: They accelerate going downhill and decelerate going uphill; they move quickly and smoothly over wide open spaces, and slowly and erratically through more congested spaces. With these ideas in mind, the fundamental motivation guiding the development of *dS* was to create an artistic installation that enables humans to have a real-time immersive experience of "becoming" energy landscapes, reinforcing the fact that our aesthetic of the invisible world must be expanded to include the notion of microscopic dynamism. To accomplish these goals, we implemented the same algorithms and mathematics normally associated with research-level atomic dynamics.

SYSTEM IMPLEMENTATION

At the heart of the *dS* system is a rigorous scientific simulation based upon Hamilton's equations of motion (a common mathematical framework used to study the dynamics of classical and quantum molecular systems). Within the *dS* software, the Cartesian coordinates of up to 30,000 simulated atoms are computed at 60 frames per second with dedicated software that has been optimized to run on a high-performance workstation equipped with an array of graphical processing units (GPUs). As with conventional atomic simulations, the internal force exerted on each atom is calculated from its pairwise interactions with every other atom in the simulation. In addition, *dS* introduces human interaction by summing this internal force with an external force derived from a composite depth image captured from an array of up to 10 depth sensors (either Microsoft Kinect or Asus Xtion sensors). An interpolated representation of this depth image is realized within the simulation as a dynamic energy landscape, the ebbs and flows of which correspond to people's movements within the space. The resulting effect enables participants to sculpt the dynamics of the atomic ensemble in real time. For a comprehensive overview of the algorithms, mathematics and implementation that underlie this process, see Glowacki et al. [19].

The simulation is graphically rendered and displayed on a large projection screen on which users can observe their energy fields, along with the waves, ripples and vibrations created as their motion perturbs the atomic simulation. A schematic illustration of a forthcoming *dS* installation space is shown in Fig. 2. The depth sensors are positioned at the center of the space, and the projector array is suspended from the ceiling. The *dS* software interface provides users with access to a number of controls that enable real-time modification of parameters related to the physics simulation and its subsequent visualization. For example, users can control a range of physics parameters, including the number of atoms, their size, the simulation temperature and the polarity and strength with which atoms "feel" people's energy fields. Users may also control visualization parameters such as the brightness of collision events, how the time history of each atom's path (atom trails) is rendered, the extent to which users are able to see their energy fields, and color palettes for all visualization elements. Different physics and graphics parameter combinations result in an enormous diversity of simulation states, a few of which are reflected in the Article Frontispiece, Figs 3, 4, 6, 7 and the issue front cover. In addition to visuals, *dS* also generates an accompanying soundscape, which is created by identifying transient structures and vibrations that arise as users manipulate the atomic dynamics. A range of analysis methods is used to provide a sonic analogue of the atomic motion. Some of these methods are mathematically identical to the spectroscopic techniques that chemical physicists commonly use to analyze matter in molecular dynamics experiments (hence the name *spectroscopy*). The feedback cycle (users affect atomic dynamics, atomic dynamics affect visuals/sound and visuals/sound affect users) gives users a textured visual and sonic experience of their interactions with the system.

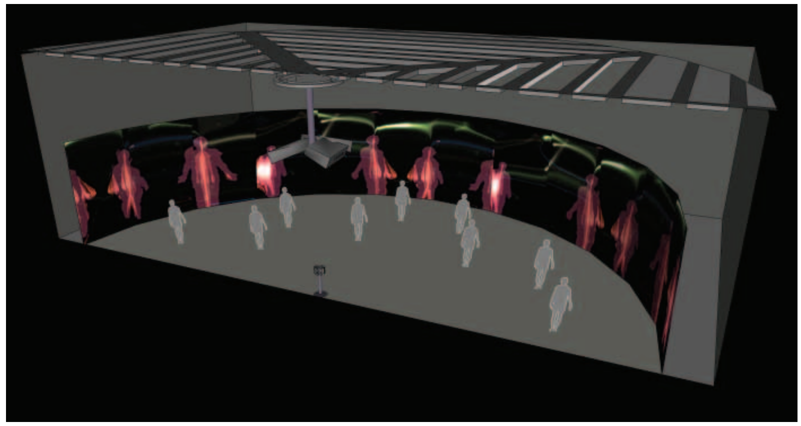

Fig. 2. *danceroom Spectroscopy* installation space showing capture from 4 depth sensors and graphics rendering to 3 displays. (© Interactive Scientific Ltd. Image: David Glowacki.)

Fig. 3. Photograph taken at a *dS* public installation at the 2012 Cultural Olympiad. (© Interactive Scientific Ltd. Photo: Paul Blakemore.)

Fig. 4. Photograph of a dance workshop taken at the *dS* Festival 2013. (© Interactive Scientific Ltd. Photo: Paul Blakemore.)

PRESENTATION FORMATS

danceroom Spectroscopy has been used in a number of scientific applications: as a platform for scientific education (e.g. teaching children and adults about how molecular dynamics impact climate change) as well crowdsourcing scientific questions related to the dynamics of biomolecular systems. An interesting by-product of our work is the fact that the equations that we derived to build the algorithmic framework for this system produce an extremely fluid, responsive and stable interactive particle simulation. The system is so robust that it is possible for users to interactively manipulate a real-time protein dynamics simulation [20]. These scientific applications of *dS* are described fully in Glowacki et al. [19]. The emphasis in this article is on how *dS* functions within an artistic context, where it has been deployed in two different capacities: (1) as an interactive installation for the public and (2) as an artistic tool providing the visual, sonic and choreographic fabric that knits together a dance performance called *Hidden Fields*.

PUBLIC INSTALLATION

We initially developed *dS* as a fully immersive, interactive installation with the graphics projected onto a surface that completely encircles the audience. This installation format is shown in the Article Frontispiece and Fig. 4 within a 21-meter, 360° geodesic projection dome installed at the London 2012 Cultural Olympiad and the 2013 *dS* Festival, a sci-arts festival held in Bristol, U.K., exclusively devoted to *dS*.

The entire 360° space can be captured and coupled to the simulation in real time. The resulting visualization is then mapped onto the interior surface of the dome via five projectors. A single landscape image of the entire visualization,

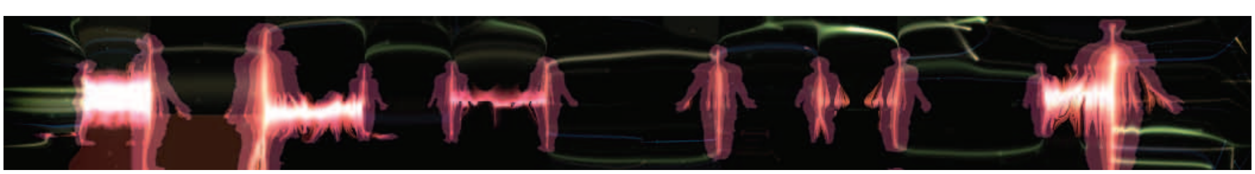

Fig. 5. Single landscape capture of the dome projection taken during a public installation at the *dS* festival in Bristol. (© Interactive Scientific Ltd. Image: David Glowacki.)

simultaneously derived from eight depth sensors, is shown in Fig. 5.

As shown in Fig. 2, participants' "energy fields" are positioned on the projection surface in front of them. *danceroom Spectroscopy* may be described as a form of "mirrored atomic sandbox," in which people can use their fields, either individually or in collaboration with others, to sculpt the system dynamics. During public installations, we automatically cycle through a series of states to display a range of physics, graphics and sonic settings (a "state" refers to a unique combination of the parameters that determine the interactive and aesthetic response of *dS*). In addition to unstructured installations, *dS* has also been used to provide an environment for contact improvisation dance workshops and yoga classes.

DANCE PERFORMANCE—*HIDDEN FIELDS*

Dance is perhaps particularly well suited to cross-fertilization with the sciences, given that it has a well-developed vocabulary for describing movement and dynamics [21]. For example, dancers and choreographers frequently use terminology that suggests a manipulation of time, space and energy—three concepts that form the foundations of scientific thinking. Similarly, chemists and biochemists often invoke choreographic and dance analogies to describe the dynamics of molecular systems, referring to molecular "dancefloors" [22] or biochemical "choreographies" [23].

Hidden Fields is a dance performance that involves four professional contemporary dancers. It has been created specifically to exploit and drive forward the implementation of the *dS* technology. Originally developed in 2012, the piece was reworked in 2013 during an 8-week series of intensive workshops involving dancers, choreographers, digital artists, sound artists, composers, computer scientists and physicists. The choreography, technology, visuals and music were arranged to loosely follow a four-part narrative that contemplates the different levels at which matter is organized and explores the dynamic processes that drive its formation and dissipation. The mantra that we adopted to capture the vision for the piece was taken from a quotation attributed to the Buddha in the *Heart Sutras:*

> All the many things in the universe are appearances of collections. Therefore, things themselves do not exist, and collections of things do not exist either [24].

At a typical *Hidden Fields* performance, audience members receive program notes containing the above quote along with a brief introduction to the *dS* system. Following a short verbal description of the underlying science and technology, the 50-minute dance piece begins. At the end, audience members are invited to enter the space and experiment with the system for themselves. Several photographs of *Hidden Fields* are shown in Figs 6, 7 and the issue front cover).

Fig. 6. Photograph of the *Hidden Fields* performance taken at the 2013 Seeing Sound Symposium. (© Interactive Scientific Ltd. Photo: Paul Blakemore.)

Fig. 7. Photograph of the *Hidden Fields* performance taken at the 2013 Seeing Sound Symposium. (© Interactive Scientific Ltd. Photo: Paul Blakemore.)

ARTISTIC REFLECTION

Since 2011, *dS* and *Hidden Fields* have been deployed in a range of international venues, including Germany's ZKM | Centre for Art and Media Technology, London's Barbican Arts Centre, the London 2012 Cultural Olympiad, San Francisco's Z-Space performing arts venue and New York City's World Science Festival. At several of these events, we have carried out a range of feedback and data-gathering activities from audiences. In what follows, we have broken these observations down into two broad categories. First are observations that have arisen during the process leading to *Hidden Fields*, where *dS* serves as an artistic tool and as the collaborative glue facilitating interaction between the components of a dance performance. Second are observations made from preliminary analysis of feedback forms collected during public installations.

DETERMINISM AND CHAOS: INTUITIVE ENTROPY

Hidden Fields raised interesting issues concerning the relationship between determinism and chaos. Choreography and dance often tend to follow structures that are linear and deterministic. *dS*, however, is characterized by stochastic noise rather than deterministic certainty [25]. This is primarily due to the so-called "butterfly effect," which gives rise to instabilities in the numerical simulation of dynamical systems. This chaotic noise distinguishes *dS* from other interactive art tools, which are often more obviously guided by a Boolean logic. Consequently, we found ourselves exploring how choreographic, sonic and visual approaches could harness and accommodate a certain amount of implicit chaos to create emergent beauty. This required all of the collaborators to be aware that the system was not deterministic nor should it be expected to behave as such, and led to a shift in emphasis: We tended to focus less on linear sequences and more on the feel and ambience of a particular system state or performance sequence. The fact that both the visual and sonic effects are generated from the dancers' motion meant that specific timings between the graphics, sonics and choreography were not emphasized nearly as much as they might otherwise have been. This permitted a certain degree of flexibility and spaciousness for facilitating interaction between the dancers, musicians, artists, programmers and choreographers [26].

Interactivity within *dS* is a delicate balance between stochastic unpredictability and deterministic certainty, what we have often referred to as *intuitive entropy*. That is, the system is noisy enough that one never quite knows *exactly* how it will respond, but deterministic enough to allow for an educated guess as to how it will *probably* respond. Many of the artists and participants at public installations mentioned this as a particularly engaging feature of the system.

FEEDBACK AND OBSERVATIONS

danceroom Spectroscopy provokes a range of reactions from its audience, although our observations and studies suggest a largely positive experience. Figure 8 shows a word cloud visualizing audience responses when external evaluators asked visitors to leave three words describing their *dS* experience. The data was compiled from over 250 participants attending one of three large-scale public installations taking place between 2012 and 2014. Although the more frequently occurring words, such as "interesting," "exciting" and "fun," suggest a favorable experience, some of the more exceptional responses were less positive. For example, the words "disturbing," "confused" and "death" are also found. References to death in particular were not uncommon, and have been highlighted in a number of conversations between installation participants and the *dS* artistic team. There are a few aesthetic features where the boundary of an individual's energy field is set to initially contain some intrinsic atomic dynamism. As variables are modified, this intrinsic dynamism dissipates, flowing from the confines of an individual's field into the wider simulation. On several occasions, installation participants have noted that this transition invokes analogies of death, as they imagine their atomic building blocks dissipating back into the environment from whence they were formed. Similar feedback from individuals who have seen *Hidden Fields* often has a distinctly metaphysical tone, hinting at how *dS* left them with a sense of interconnectedness beyond the physical boundaries of their bodies, fostering a sense of continuity with nature and with other people.

At a recent installation with approximately 1,000 attendees, we obtained further qualitative feedback from 60 public participants. Analysis of this feedback, combined with accounts of conversations between public participants and the *dS* team, showed that people were occasionally confused by abstract representations of themselves. We found that this confusion was considerably reduced by describing people's representation within the simulation as "energy avatars" rather than "energy fields." In general, installation participants consistently have the most enjoyable experience when their encounters with *dS* take them on a sort of narrative journey, transitioning from extremely literal, "person-shaped" energy fields to more abstract energetic representations. The simple states accelerate understanding of the system and make people increasingly engaged in the subsequent abstract visual and sonic states. Participants who had seen *Hidden Fields* prior to interacting with *dS* tended to be more comfortable with these abstract representations, presumably having a better understanding of the system from watching the dancers.

danceroom Spectroscopy places no constraints on the number of possible users, and some of the most interesting and beautiful results (graphically and sonically) arise when users undertake collaborative and cooperative action. Users who had seen *Hidden Fields* appeared to understand this and appeared more willing to cooperate with, and make contact with, strangers. Depth sensor positioning profoundly impacts user-user interaction and corresponding engagement with the *dS* system. Most often, we place our sensors behind the participants for side-on capture as shown in Fig. 2; however, we have also experimented with ceiling-mounted

Fig. 8. Word cloud visualizing user feedback obtained from over 250 respondents over three large-scale *dS* installations. The size of the word corresponds to its frequency in the responses. (© David Glowacki)

cameras pointing downward, for top-down depth capture. While this is a less convenient arrangement, it noticeably increased user-user interaction, most likely because it places users on relatively equal footing. In *dS*, the strength of a user's energy field is proportional to their distance from the sensor. For side-on mounting arrangements, it often happens that a small number of users (knowingly or unknowingly) dominate the system, standing in front of the camera and "stealing" everybody else's atoms. In the top-down arrangement, this user dominance is less likely to occur.

Users often reported an enhanced *dS* experience when provided with some sort of explanation about the underlying processes and scientific background to the content, particularly when it is emphasized that the particle dynamics derive from research-grade algorithms in molecular dynamics. The scientific link seems to captivate audiences and adds considerable depth to their interpretations. Some of the feedback from *dS* users who had seen *Hidden Fields* specifically mentions that the background given prior to the *Hidden Fields* performance increased their appreciation of the system and their experience within it. It is for this reason that we often make an effort to communicate the scientific underpinnings of *dS*, in the form of both brief lectures and information sheets.

CONCLUSIONS

This paper provides an overview of *danceroom Spectroscopy*, an interactive audiovisual installation and dance performance built on research-grade atomic physics algorithms. Built from rigorous algorithms and analogies used to describe and simulate atomic dynamics, *dS* runs using dedicated GPU-accelerated software on a high-performance computational platform with up to 10 depth sensors. The system has been used to create an interactive installation and dance performance entitled *Hidden Fields*, which has been deployed in leading arts centers and cultural institutions in Europe and North America.

Reactions to *dS* indicate significant user engagement with the system, as well as considerable lateral (i.e. user-user) interaction. On an institutional level, *dS* has also been judged to be aesthetically compelling, as indicated by the six awards it received from January 2013 to July 2014, in sectors spanning media, arts and science. Ongoing user studies and continued development will allow the system to be improved as an artistic platform, audience experience and educational platform. The physics engine running *dS* is robust and may be used to simulate a range of interactive visual and sonic effects beyond atomic physics. In the future we plan to explore these opportunities.

With growing applications of computer science in both art and science, interactive technology increasingly offers a fascinating and nontraditional site for linking artists and scientists, and suggests new ways to imagine the dynamism of the invisible world. This opens up an exciting horizon of future content: As nearly all of physics and much of chemistry are cast in terms of field equations, a robust algorithmic framework for realizing humans as "fields" within scientifically rigorous simulations offers great potential to further explore the boundaries between aesthetic representation and scientific imagination. Possibilities for cross-fertilization abound on this frontier, and where they will lead is an open and exciting question.

Acknowledgments

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