ARTNANO

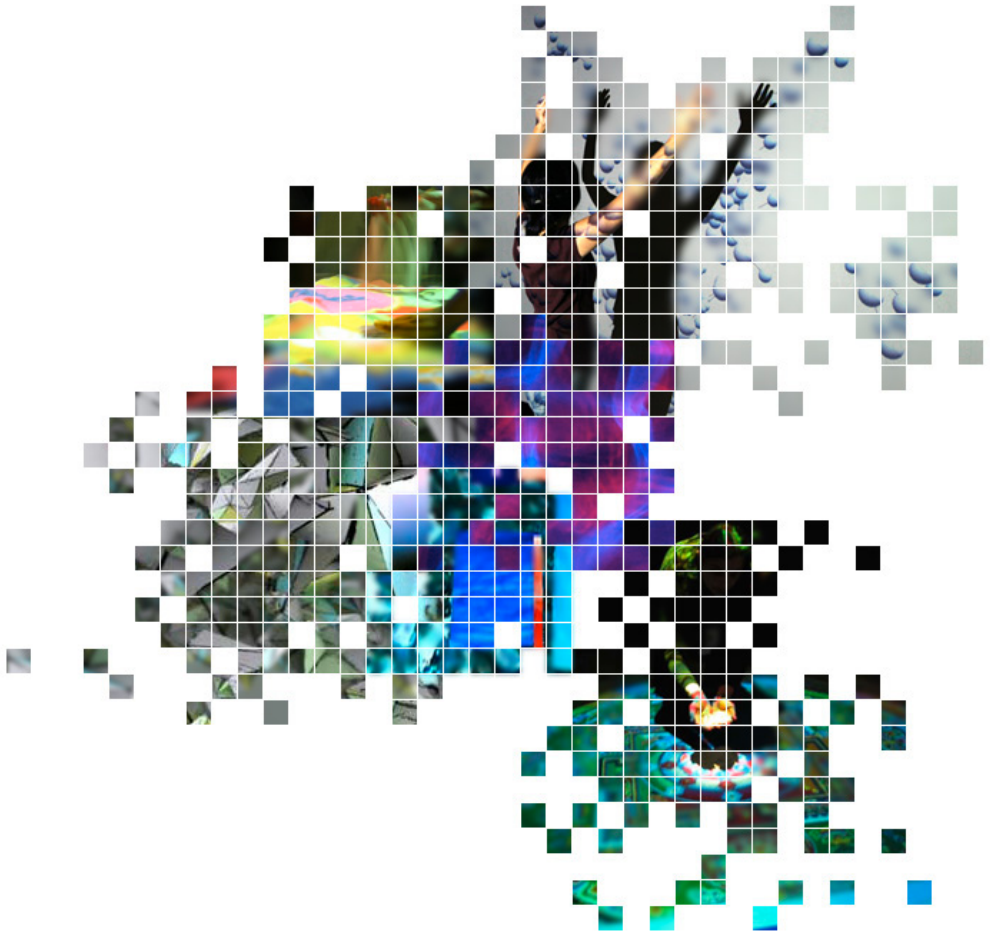
NISE network NANOSCALE INFORMAL SCIENCE EDUCATION

exploratorium

Artists Visualizing the Nanoscale at the Exploratorium

How do we picture a world we can't see? How do we envision a place where gravity is barely relevant and everything is in constant motion? The nanoscale is so small it cannot be seen directly, so tiny that its dominant forces are different than those we are used to in everyday life.

To address this challenge, the NISE Network Visualization Laboratory at the Exploratorium invited artists and scientists to explore ways of representing the nanoscale through a series of commissions, installations, and residencies in 2006. Drawing from a spectrum of artistic media and approaches, the results of these experiences are documented on this website.



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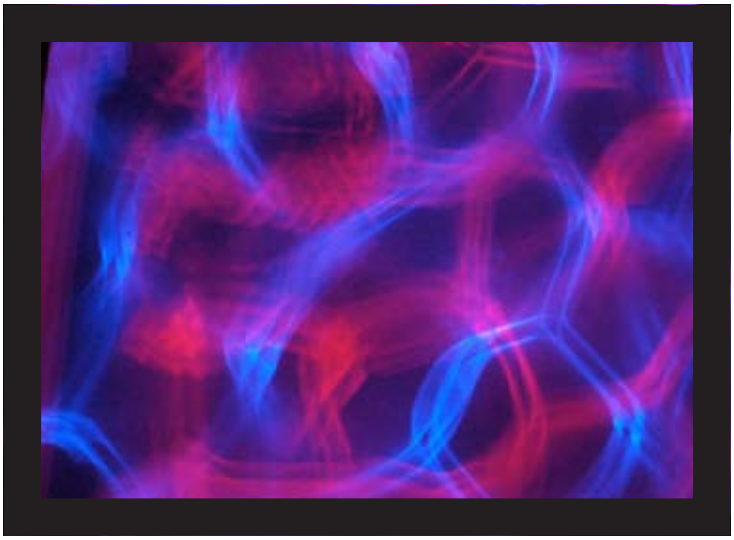
ERIC HELLER

Eric Heller

Eric Heller is a professor of physics at Harvard University and an artist who was invited to the Exploratorium for a week-long residency in 2006. While at the Exploratorium, he was joined by colleague and fellow scientist Don Eigler, a physicist known for his imaging of the *quantum corral*. With Exploratorium staff, Heller constructed an experimental display of quantum waves to create a human-scale immersive experience for museum visitors that mimicked the nanoscale phenomenon.

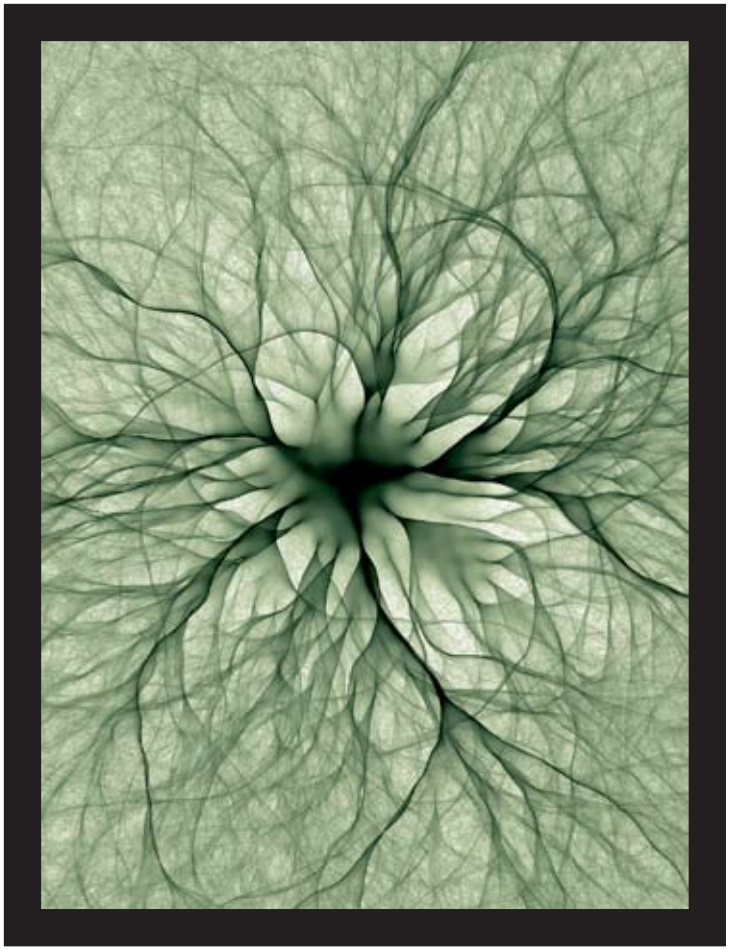
During his residency, Heller also participated in discussions with filmmaker Stephanie Maxwell and in a lecture in which he discussed the source material for his 2D computer simulations such as the electron flow patterns seen in *Transport II*.



Untitled (stereo ripple tank) (2006)
Mixed media: LEDs, water, transparent tank, ladders, 3D glasses. Photo: Eric Heller

The main effect of this work was created by projecting powerful LED lighting through a transparent tank of water onto the floor. The tank was hung well above viewers' heads. As ripples were created by a bobber in the tank, viewers wearing red and blue 3D glasses saw a representation of colliding water waves — not unlike quantum waves at the nanoscale — projected onto the floor. As Heller describes it, "It was awesome; if you stood in the right place and looked down with the glasses on, it looked as though the waves were about waist high and you were wading!"

ERIC HELLER



Transport II (electron flow paths) (2001)
High-resolution digital print. Photo: Eric Heller

Transport II shows a theoretical simulation of the flow pattern of electrons traveling over a nanoscale landscape. The electrons are trapped in a sheet at the interface between two solids. Such sheets of electrons are of great importance in cutting-edge electronics. The total area seen here corresponds in size to that of a typical bacterium. The bumpy landscape that the electrons must negotiate is caused by the irregular arrangement of positively charged "donor" atoms in a layer just above the flat interface in which the electrons are traveling. The electrons are attracted to regions with more positive charges nearby; since these charges are randomly arranged, the electrons negotiate hills and valleys of repulsion and attraction. The cumulative effect of many such encounters results in the pattern seen here. This image comes from a numerical simulation that closely approximates what is seen experimentally with an extremely sensitive scanning probe microscope that can sample thousands of distinct places inside a tiny space.

Artists

ERIC HELLER

Biography

Eric Heller was born in Washington, D.C. in 1946 and educated in Minnesota. He received a PhD in chemical physics at Harvard in 1973, and afterward held faculty positions at UCLA and the University of Washington. From 1993 to 1998, Heller was Director of the Institute for Theoretical Atomic and Molecular Physics at Harvard University, and professor of physics at Harvard. From 1998 to the present, Heller has been a professor of physics and chemistry at Harvard.

Eric Heller's research focuses on quantum mechanics, scattering theory, nanophysics, condensed matter physics, and quantum chaos. A recurrent theme in Heller's work involves various aspects of the *correspondence principle* (which focuses on the relationship between quantum mechanics and classical physical descriptions of the behavior of matter) and semiclassical approximations in a variety of physical problems, including nonlinear dynamics and chaos theory.

Heller is also an artist, producing large-format, computer-generated works based on his research. Over 50 articles on his works have been published in various magazines, and his exhibits include several traveling solo and group shows and works in many private and public collections.

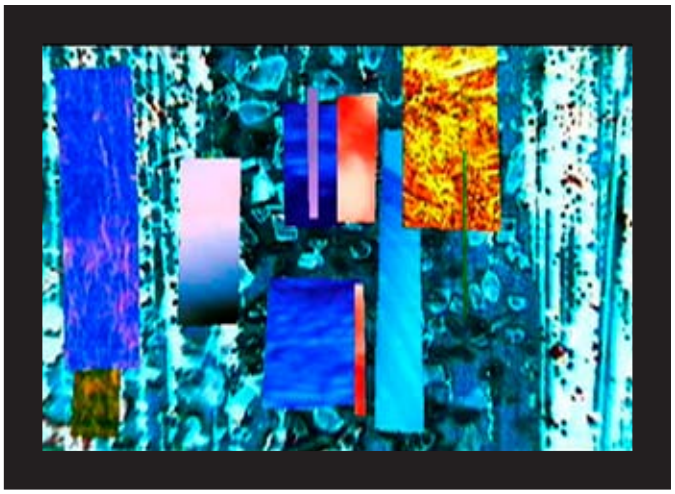
Heller is a fellow of the American Physical Society, the American Academy of Arts and Sciences, and the American Association for the Advancement of Science. He is also an elected member of the International Academy of Quantum Molecular Science and the National Academy of Science.

http://monsoon.harvard.edu/

STEPHANIE MAXWELL

Stephanie Maxwell

Stephanie Maxwell is an animation filmmaker who was invited by the Exploratorium's film program for a short residency in the spring of 2006. While Maxwell's films are not specifically about nanoscale science, the Exploratorium staff saw the potential for her work to reference qualities of the nanoscale. Achieved through an animation process that directly alters the film surface with paint and other media, the highly energetic and rapid motion of abstract forms in her films evokes a state of constant motion consistent with the nanoscale environment.



Trailer from *All That Remains* (2006)
Animated film. Musical score by Michaela Eremiasova. (6 min.)

All That Remains is an intricate mosaic of sequences of animated abstract images and musical passages that create a chaotic yet tightly choreographed portrayal of figurative matter in perpetual decomposition. The sound consists of dynamic and evolving patterns of musical textures and phrases. Dense masses of granular "particles" often converge to create progressive patterns of movement, which alternate with recurring looped vocal passages. The animated imagery was created through a multitude of experimental processes, including video 'rephotography' of direct-on-35mm-film animated sequences (painting and etching imagery direct on 35mm clear and black film stocks), object animation, handmade animated mattes, and 'animated rephotography' of live action sequences. The imagery was composited and edited in digital post-production.

STEPHANIE MAXWELL

Trailer from *Runa's Spell* (2007)
Animated film. Musical score by Michaela Eremiasova. (3.5 min.)

Runa's Spell conveys a moment of connectedness with the sensual persuasions of an imaginary world. Image and music interact in a dramatic way to deepen and enhance the perception of enchantment and longing. The visuals consist of digitally interwoven and layered animated hand-paintings on 35mm film stock, animated objects and cutouts, and pixilation of live creatures. The music attempts to create a spiritual sense of journey through the fractional evocation of ancient Egyptian folk song. The sonorous texture of trembling and contorted images illustrate the hesitation, solitude, and endless dreamscape of the human mind.

From concept through realization, both *All That Remains* and *Runa's Spell* are collaborative works by animator Stephanie Maxwell and composer Michaela Eremiasova.

STEPHANIE MAXWELL

Biography

Stephanie Maxwell is a professor in the School of Film and Animation at the Rochester Institute of Technology in Rochester, New York. Her teaching includes courses in film, video and animation production (including experimental processes) and the history of animation. She has curated and presented film programs internationally and taught abroad on several occasions. Ms. Maxwell has been producing her unusual animated works for over 15 years. Her award-winning work has been shown at international film, multimedia, and television programs and festivals.

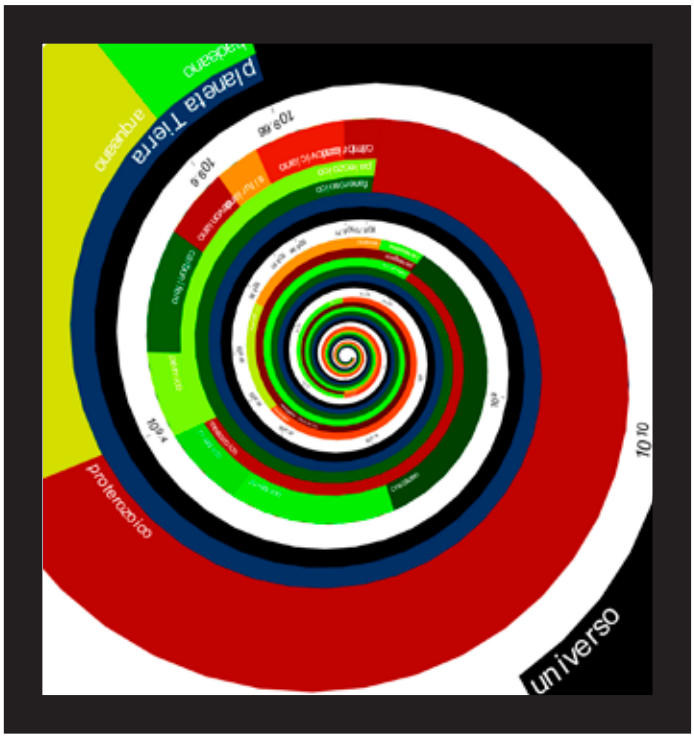
On these works, Maxwell collaborated with composer Michaela Eremiasova. Born in Prague, Eremiasova is pursuing a PhD in composition at the Eastman School of Music and previously studied at the Berklee College of Music in Boston. Michaela co-orchestrated the opera *West-The Future of the American Musical Theater* by Broadway composer Charles Strouse (commissioned by the Hanson Institute for American Music). She has received other commissions as well, most notably for ensembles including the Novus Trombone Quartet, Russell Scarbrough's Big Band, Eastman Trombone Choir, and the Beohmler Foundation. Michaela has also composed music for film and animation works, including Cat Ashworth's documentary *Beating the Biological Clock* and the animated opera *Car Crash Opera* by Skip Battaglia.

http://people.rit.edu/sampph/

SANTIAGO ORTIZ

Santiago Ortiz

Santiago Ortiz's two-week Exploratorium residency allowed him to share his interactive visual models of linear scale that imagine time and size scales along a very large continuum. During his visit, he met with Exploratorium staff, scientists, and other visiting artists, and spent much of his time in the Learning Commons developing sketches for Flash prototypes. Ortiz's scale models attracted Exploratorium staffers because the nanoscale is difficult for many visitors to envision, and these interactive pieces offered potentially engaging models of the concept of size at the nanoscale.



Spiral del Tiempo (Time Spiral) (2005)
Flash graphics. In colllaboration with Luis Rico and Lynn Margulis.

Santiago Ortiz's *Spiral del Tiempo* was developed in collaboration with designer and artist Luis Rico and biologist Lynn Margulis after the team had been experimenting with interactive zooms in a conventional straight line (e.g., time flowing from one end of the line to the other). The spiral was a compelling next strategy in that it relates both to Western and Eastern cultural sensibilities, in both ancient and modern times. With *Spiral del Tiempo*, users pass through eras of geologic time represented by the spiral. The present time is at the center, and time expands in each section approximately by factors of 10.

SANTIAGO ORTIZ

Espacio Escala (Scale Space) (2005)
Flash graphics. In collaboration with Luis Rico and Lynn Margulis.

Like *Spiral del Tiempo*, *Espacio Escala* draws its inspiration from Charles and Ray Eames' film and book *Powers of 10*. *Espacio* is an interactive experience simulating the travel of several beings and celestial bodies in exponents of 10. This piece combines scale ladders and zooms, forms often used to portray inaccessible time or size scales. By navigating with a scale ladder, a diagram that often includes a ruler to show relative size, users can zoom through different size scales. While the size scales are not precise, the core idea is to approximate an experience evocative of the wide spectrum of scale relations between living organisms.

SANTIAGO ORTIZ

Biography

Born in 1975 in Bogotá, Colombia, Santiago Ortiz studied mathematics, music, and literature at the Universidad de los Andes in Bogotá. He has taught in the School of Fine Arts at the University of Porto in Portugal and in the Department of Arts and Mathematics at the Universidad de los Andes. He was a professor of art and technology at the European University of Madrid and teaches classes in digital design at Madrid's European Institute of Design. He is also co-founder of *Blank*, a magazine of digital art and culture, and a regular collaborator with Medialab Madrid; and he recently founded the artist collective Bestiario. He lives and works in Lisbon and Barcelona.

Santiago Ortiz collaborates with artist, designer, and producer Luis Rico and biologist Lynn Margulis. Luis Rico is the co-director of Cibervisión 02, the International Festival of Art, Science and Technology, and MediaLab Madrid (Conde Duque Cultural Centre, Madrid). He studied graphic and industrial design at the Elisava School in Barcelona. In the 1980s, he took up painting; his work was included in exhibitions in Abidjan (Ivory Coast), Valencia, and Majorca. He is the co-author and co-director of the itinerant Banquete project (Palau de la Virreina, Barcelona; ZKM Karlsruhe; and Conde Duque Cultural Centre, Madrid, 2003), as well as the interactive teaching project Yumga ga, sponsored by UNESCO. He is also director of the Fundación Banquete and co-organizer of Cibervisión 99 at Madrid's Universidad Rey Juan Carlos.

Dr. Lynn Margulis is a professor in the Department of Geosciences at the University of Massachusetts in Amherst. Her contributions to our understanding of cellular processes include her theory on the origin of eukaryotic organelles.

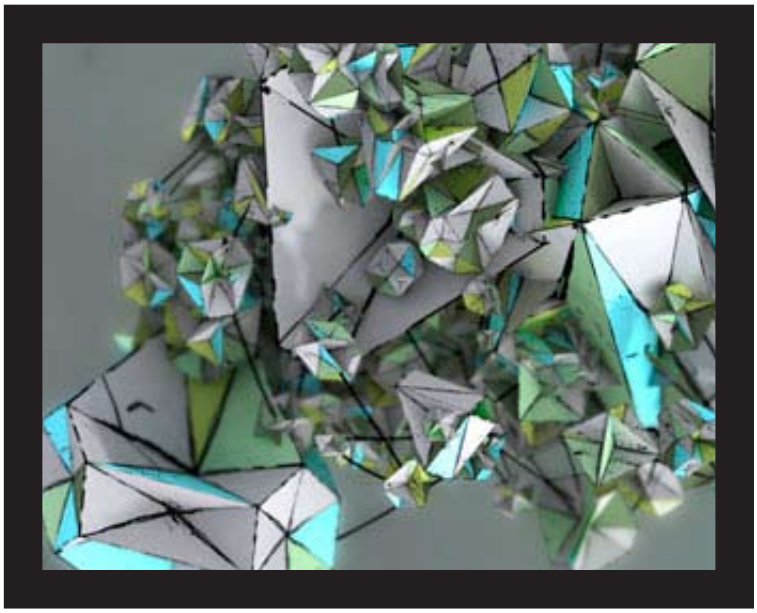
http://moebio.com/santiago/

SEMICONDUCTOR

Semiconductor

Ruth Jarman and Joseph Gerhardt

In 2006, the Exploratorium's film program presented Semiconductor's *200 Nanowebbers* in the exhibition *In the Land of the Lilliputian: Artists Visualize the Very Small*. For *200 Nanowebbers*, Semiconductor created an aural and visual space suggesting what it might feel like to be a part of the nanoscale world. Using abstract hand-drawn animation synchronized to an eclectic audio track (designed by Double Adaptor), the motion and randomness of movement at the nanoscale are evoked in an immersive and imaginary environment.



200 Nanowebbers (2005)
Digital video animation. Audio by Double Adaptor © Osaka Recordings

For *200 Nanowebbers*, Semiconductor created a molecular web that is generated by Double Adaptor's live soundtrack. Using custom scripting, the melodies and rhythms spawn a nanoscale environment that shifts and contorts with the audio resonance. Layers of energetic hand-drawn animations play over simple vector shapes forming atomic-scale associations. As the landscape flickers into existence by the light of trapped electron particles, substructures resembling crystalline substances begin to take shape.

SEMICONDUCTOR

Biography

Ruth Jarman and Joseph Gerhardt

Semiconductor make moving images which reveal our physical world in flux: cities in motion, shifting landscapes, and systems in chaos. Since 1999, UK artists Ruth Jarman and Joe Gerhardt have worked with digital animation in an attempt to transcend the constraints of time, scale, and natural forces and explore the world beyond everyday experience. Central to these works is the role of sound, as it creates, controls, and deciphers images, exploring resonance through the natural order of things.

Semiconductor's work has been exhibited at the Tate Britain, ICA London, San Francisco Film Festival, Mutek Montreal, and the Venice Biennale, among other venues worldwide. In 2001, they released their works on DVD. This release was followed up with *Worlds in Flux*, a DVD on Fat Cat Records that accompanies their 2007 UK touring exhibition *Brilliant Noise*. Recent fellowships and residencies have supported site-specific work, including research and experimentation at the NASA Space Sciences Laboratories of UC Berkeley in California.

http://www.semiconductorfilms.com/index.html

SCOTT SNIBBE

Scott Snibbe

In 2006, the Exploratorium commissioned Scott Snibbe to produce *Three Drops* as a project for the NISE Network. A life-size interactive media installation, *Three Drops* shows how different forces of nature can be observed at different scales.

Three Drops (2006)
9' x 20', digital video projection (digital projector, retro-reflective screen, custom digital video camera, custom software)

In *Three Drops*, visitors walk in front of a video projection to see how their shadows affect simulations of water at vastly different scales. In one segment, falling water is shown at human scale, and gravity is the noticeable force. The piece then zooms into a single drop of water. Here, visitors are immersed in an environment where they are about one thousand times smaller than normal and time passes about one hundred times more slowly than in actuality. At this scale, visitors explore how surface tension makes water behave. In the third segment, the piece zooms into the droplet of water to show individual water molecules at the nanoscale. Here visitors experience a world about one billion times smaller than normal, and time is slowed by a factor of one trillion. At this scale, visitors interact with individual water molecules and see how electric charges attract water molecules to viewers' shadows.

SCOTT SNIBBE

Biography

Scott Snibbe creates immersive interactive art known for its positive social effects: fostering a sense of interdependence, promoting social interaction among strangers, and increasing viewers' concentration. His artworks have been installed in institutions worldwide, including the Whitney Museum of American Art in New York, the InterCommunications Center in Tokyo, Austria's Ars Electronica, the Institute of Contemporary Arts and the Science Museum in London, the Phaeno Science Center in Germany, and the Cité de Science in Paris. He has been awarded a variety of international prizes, including the Prix Ars Electronica and a Rockefeller New Media Fellowship. In 2007, he became one of only a few artists ever to have been awarded a National Science Foundation Grant, for research in interactive narrative. He is the founder of Snibbe Interactive, Inc., a company that sells and distributes interactive installations for public spaces; and Sona Research, a company that engages in educational and cultural research.

Snibbe was born in 1969 in New York City. He holds Bachelor's degrees in computer science and fine art and a Master's in computer science from Brown University. Snibbe studied experimental animation at the Rhode Island School of Design, and his films have been widely shown internationally. He has taught media art and experimental film at Brown University, the San Francisco Art Institute, California Institute of the Arts, the Rhode Island School of Design, and UC Berkeley. Snibbe worked at Adobe Systems as a computer scientist, where he made substantial contributions to the special effects software Adobe After Effects and other research projects. Snibbe has also held research positions at Interval Research, where he performed basic research in haptics, computer vision, and interactive cinema. Snibbe's research is documented in a number of academic papers. He holds over a dozen patents.

http://www.snibbeinteractive.com/

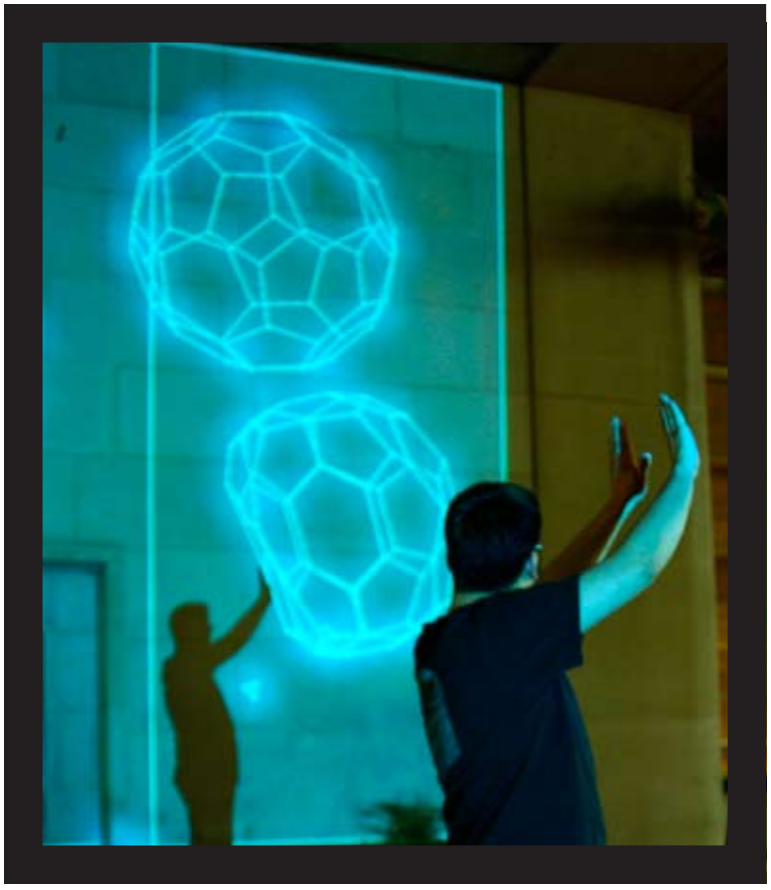
VICTORIA VESNA

Victora Vesna

My inspiration comes from the wonder of seeing how nature works from the bottom up and how complexity evolves. I am excited at the fact that [nanoscale science] has the potential of bringing us closer to cooperating with nature in building and changing the world. Ultimately we are the most amazing nano-beings–we all start with a seed and egg and then become complex beings interrelated with everyone and everything around us. My goal is to bring this realization and change of perception of our bodies and our selves that holds the possibility of a major paradigm shift. - Victoria Vesna

Working collaboratively with scientist James Gimzewski, Victoria Vesna is known for her conceptual multimedia artworks that ask audiences to reflect on their personal relationships to–and the philosophical implications of–the scientific principles evoked in her work. Nanoscale science holds a particular interest for her, and she has developed several interactive video installations and artworks on the subject, two of which were presented at the Exploratorium. *Nanomandala* was presented in 2005 on the occasion of the First Annual NISE Conference in San Francisco. *Zero@wavefunction* was included in the 2006 Exploratorium exhibition *In the Land of the Lilliputians*.

VICTORIA VESNA

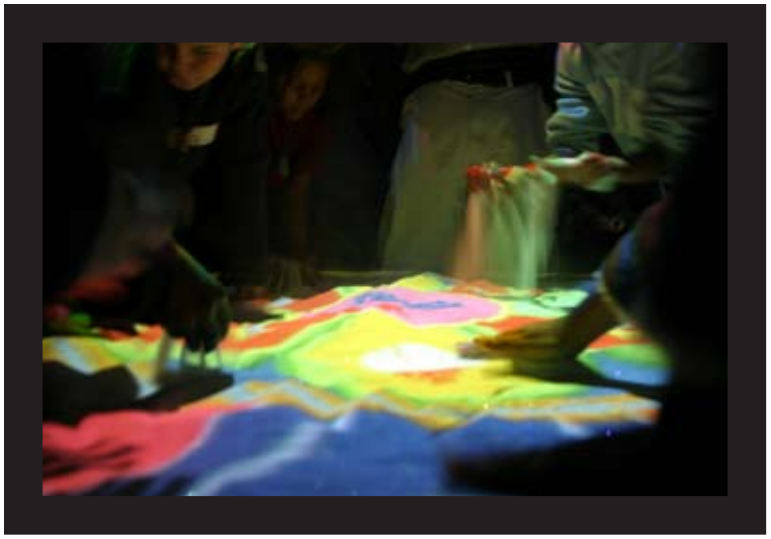


Zero@wavefunction (2002)
Interactive video projection. In collaboration with Jim Gimzewski; software designed by Josh Nimoy.

Albert Einstein's greatest contribution to humanity is the discovery that matter and energy are inter-convertible. Matter appears, changes, and disappears; nothing, not even a rock, is really solid. The atoms and electrons in a rock are subtle and alive, just as the ocean is. These particles are described in quantum mechanics by a complex function known as a *wave function*. A wave function contains all the probabilities and energetic possibilities of particles: space, energy, and sometimes time itself. These wave functions are basically connected, and when two come close, they are both changed. In fact, they have a probability to create nothing: zero.

The interactivity of *Zero@wavefunction* is based on the way a nanoscientist manipulates an individual molecule, billions of times smaller than common human experience but projected on a relatively monumental scale. When a person passes, they cast a larger-than-life shadow on the molecule and activate responsive buckyballs. The visualizations are of buckyballs that respond via sensors to the movement of the person's shadow, and the possibility of manipulating the molecule emerges.

VICTORIA VESNA



Nanomandala (2003)
Interactive video projection on a bed of sand. In collaboration with Jim Gimzewski and Tibetan monks.

Nanomandala consists of a video projected onto a disk of sand, 8 feet in diameter. Visitors touch the sand as oscillating images are projected of the molecular structure of a single grain of sand, achieved by means of a scanning electron microscope (SEM), to the recognizable image of the complete mandala, and then back again. This coming together of art, science, and technology is a modern interpretation of an ancient tradition that consecrates the planet and its inhabitants to bring about purification and healing.

Inspired by watching the nanoscientist at work, purposefully arranging atoms just as the monk laboriously creates sand images grain by grain, this work brings together the Eastern and Western minds through a shared process centered on patience. Both cultures use these bottom-up building practices to create a complex picture of the world from extremely different perspectives.

VICTORIA VESNA

Biography

Victoria Vesna is a media artist and professor in the Department of Design/Media Arts at the UCLA School of the Arts. She is also director of the recently established UCLA Art/Sci Center and the UC Digital Arts Research Network. Her work can be defined as experimental creative research that resides between disciplines and technologies. She explores how communication technologies affect collective behavior and how perceptions of identity shift in relation to scientific innovation. Her most recent installations–*Blue Morph*, *Mood Swings*, and *Water Bowls*–all aim to raise consciousness around the issues of our relationship to natural systems. Other notable works are *Bodies INCorporated*, *Datamining Bodies*, *n0time*, and *Cellular Trans_Actions*.

Vesna has exhibited her work nationally and internationally in numerous solo exhibitions and group shows. She has published dozens of articles and lectured widely. She is the recipient of many grants, commissions, and awards, including the Oscar Signorini Award for best net artwork in 1998 and the Cine Golden Eagle for best scientific documentary in 1986. Vesna's work has received notice in numerous publications, such as *Art in America*, *National Geographic*, the *Los Angeles Times*, *Spiegel* (Germany), *The Irish Times* (Ireland), *Tema Celeste* (Italy), and *Veredas* (Brazil), and also appears in a number of book chapters on media arts. She holds a PhD from the University of Wales and is the North American editor of *AI & Society* and author of *Database Aesthetics*.

James Gimzewski is a professor in the Department of Chemistry and Biochemistry at UCLA. Until February 2001, he was a group leader at the IBM Zurich Labs, where he was involved in nanoscale science beginning in 1983. He pioneered research on electrical contact with single atoms and molecules, light emission, and molecular imaging using the STM. His accomplishments include the first STM-manipulation of molecules at room temperature, the realization of molecular abacus using buckyballs, the discovery of single molecule rotors, and the development of nanomechanical sensors, which explore the ultimate limits of sensitivity and measurement. Recently, he discovered a new method to make the world's most perfect carbon nanotube crystal. His current interests are in the nanoarchitectonics of molecular systems and molecular and biomolecular machines–in particular, those with quantum mechanical possibilities for information processing.

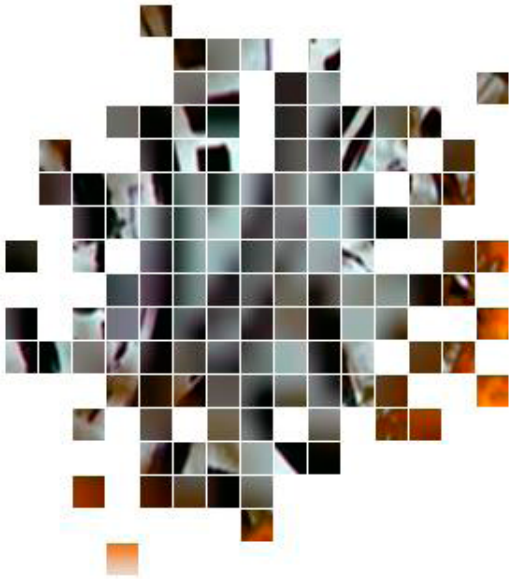
Gimzewski received the 1997 Feynman Prize in Nanotechnology, the 1997 Discover Award for Emerging Fields, the 1998 Wired 25 Award from *Wired* magazine, and the Institute of Physics Duddell 2001 prize and medal for his work in nanoscale science. He holds two IBM Outstanding Innovation Awards and is a Fellow of the Institute of Physics and a Chartered Physicist. Jim was elected to the Royal Academy of Engineering, and he has joined the scientific boards of Carbon Nanotechnologies, Inc. and Veeco-DI Instruments (a CNSI member company). With over 168 papers published, Professor Gimzewski's research continues to appear in journals such as *Science*, *Chemical Engineering*, and *Nature*. His work has also appeared in *Discover*, *The New York Times*, *The Wall Street Journal*, and *Scientific American*.

http://vv.arts.ucla.edu/projects/current.php

Perspectives

Tom Rockwell

Art at the Nanoscale Boundary: Reflections on Art, Education, and Culture



For most of us, comprehending science at the nanoscale takes an extreme act of the imagination. It requires conjuring up an utterly foreign and remote world populated by atoms and molecules, a place our bodies can't go and our minds are ill-equipped to grasp. Supporting this act of imagination is one of the goals of the National Science Foundation-supported Nanoscale Informal Science Education (NISE) Network. As director of exhibits at San Francisco's Exploratorium and one of the Principal Investigators of the NISE Network, I spend a considerable amount of time thinking about this goal—and I believe that achieving it is a challenge requiring the imagination, skill, and active investigation of artists as well as scientists.

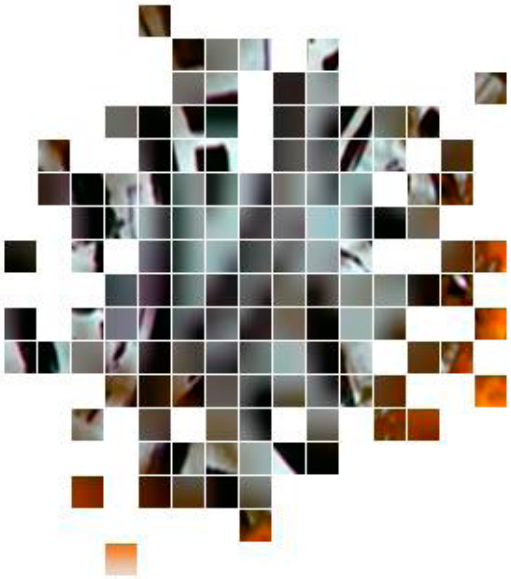
As museum educators, we often need to remind ourselves just how cognitively difficult it is to conjure up the nanoscale world. Astronomy is far easier on the mind, in part because travel and acceleration are everyday experiences: Just extrapolate from car travel to warp speed and you've begun to wrap your head around intergalactic distances. But there is no similar experiential basis for shrinking to the size of a DNA molecule. Similarly, the mental time travel of paleontology is simpler to imagine than nanoscale science, because imagining distant eras is far more natural than picturing a universe of detail inside a grain of sand. (And giant reptiles add even more to the enticement of the ancient world.)

The tales of miniature worlds found in many cultures reveal that familiarity and experience drive our hopes for shrunken realms. If the nanoscale turned out to be populated with fairies or Lilliputians, we would have a much easier time talking about it. But it is not—and we are left probing, picturing, and trying to explain a world that is hard to get to and contains little that is familiar.

All of this brings us to the need for art. Artists may be described as professional explorers of perception and imagination, people whose life's work focuses on the edges of cognition, who strive to help others see and feel new things. Unlike scientific illustrators who tend to avoid ambiguity for the sake of educational clarity, artists revel in the murky territory where aesthetics, emotions, and cultural meaning come together. Who better, then, to explore the challenging cognitive territory of nanoscale science? Who better to make the invisible not just visible, but also compelling and meaningful?

It was with this affective and cultural content in mind that the Exploratorium began in 2006 to survey artistic investigations of nanoscale science. This effort was one of several directions pursued by the NISE Network's Visualization Laboratory, a new virtual lab led by the Exploratorium and charged to build knowledge about visualizing the nanoscale. The Visualization Laboratory surveyed existing artworks and literature about art and nanotechnology, collaborated with Leonardo (*http://www.leonardo.info/leoinfo.html* a journal for and about artists that explore science and technology concepts in their work) to find interested artists, held exploratory residencies, and commissioned new prototypes. The results of these investigations make up the core of this website.

The primary goal of the Visualization Laboratory's artist collaborations is to build a greater understanding of how to portray essential qualities of the nanoscale landscape. Just as painters of portraits or landscapes seek to convey fundamental aspects of their subjects (even impressionistically or abstractly), we pursued a similar, quasi-representational approach to the art of the nanoscale.



In the course of our research, we explored what scientists and engineers considered core attributes of the nanoscale world—and different ways of representing them. We came to focus on qualities such as relative size ("nano is smaller than bacteria but bigger than atoms"), atomicity ("everything is made of atoms"), the prevalence of different forces ("gravity doesn't matter much down there"), and kinetic qualities ("everything is in motion at the nanoscale"). These simple but important ideas then became potential subjects for new artistic explorations.

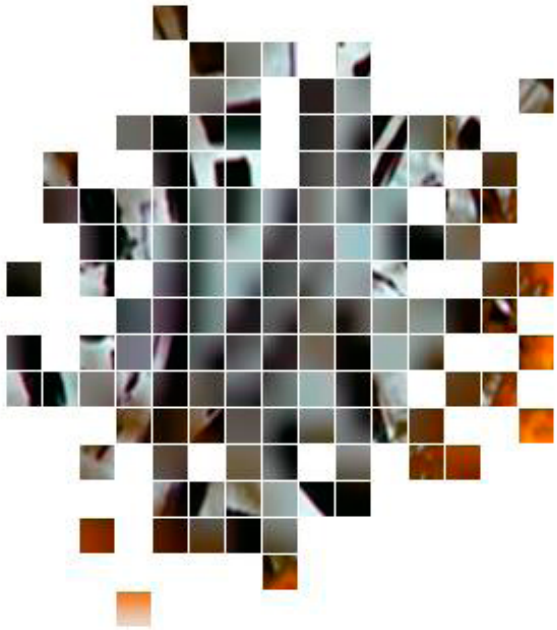
Here, however, I would like to zoom out to a broader set of questions surrounding nanoscale art, questions about potential aesthetic interest and broader cultural meaning that accompany the emergence and maturation of this new knowledge and technology. Although the Exploratorium has focused on an educational use of the arts to represent core qualities of the nanoscale, we could not avoid stumbling on these larger cultural issues—issues that may ultimately have crucial implications for broader educational efforts. Some of the broader lessons gathered from our exploration of nanoscale science and art are:

- The field of nanoscale science is young and intriguing, but also challenging and confusing. It's somewhat like a frontier town: full of exploration and start-up businesses, many of which will probably not last for long. Roles are fluid—we see scientists talking like artists about their visualizations, illustrators acting like futurists as they imagine fictional applications, and artists working as educators alongside museum professionals. What we see is typical of an early-stage intellectual/artistic development: a broad, diverse and interdisciplinary group exploring a new and well-funded topic in which content, cultural ramifications, roles, and the balance between hype and substance is still very much in flux.

- Once they are graphically manipulated and enhanced, the shapes and images of nanoscale science can have a strong abstract aesthetic appeal. Colorized micrographs, geometric arrangements of atoms, and computer simulations of electron paths are popular among scientists interested in visual aesthetics and graphic designers and art directors. It's not difficult to envision exhibitions of the "abstract world of the nanoscale" at art museums or research centers (although, given the source material for these abstractions, they would likely require considerable interpretation for the general public). The more artistic images coming out of labs draw heavily from the conventions of abstract and landscape painting and photography, and it is not yet clear how they contribute back to those artistic traditions.

- The "multi-scale zoom" has become a new cinematic/animation form ripe for ongoing artistic development. Works like Victoria Vesna's *Nanomandala* and Scott Snibbe's *Three Drops* show that scale-travel is an intriguing formal and conceptual problem. This new artistic form, which connects the human-scale perceptual world with the micro- and macro- worlds surrounding us, has become an important new feature of our visual culture. Although there have been previous educational "zooms" (starting with Charles and Ray Eames' *Powers of Ten*), I believe this form could benefit from having different artists explore how imagery and cultural resonances shift when the same object or situation is viewed at different scales. Grappling with the conceptual and cultural discontinuities across these multiple size-scales is a critical task for both art and science.

- Art, drama, and fiction have already significantly engaged emerging technologies sharing much with nanotechnology, such as genetic engineering.



Science fiction, wheather utopian or dystopian, remains one of the most engaging entry points for nanoscale science and engineering. Fantastic "what if" scenarios about new technologies and their impacts on human life are carrying the first wave of public interest in nanotechnology. Dreams of healing, immortality, and technological solutions to our burgeoning ecological fears can be found alongside nightmares about environmental disasters and nanobots run amok. I would like to see a new generation of artists, playwrights, and writers engage this discourse and continue to explore these future scenarios for what they reveal about human values, hopes, and fears.

Finally, and most importantly,

- We are still lacking compelling answers to the relevance question, the "Big Why." Who cares? Why should it matter *to me*? How many artists, educators and audiences would care about nano if it weren't so well funded? These unanswered questions pose a significant challenge. It is not enough to simply present nanoscale science and engineering as the technological flavor of the decade. Nor have epistemological issues around "seeing the invisible," however intriguing they may be, risen to the level of an essential cultural topic. If this work is indeed broadly relevant, I think that relevance centers on the fact that it is at the nanoscale where physics and chemistry become the material world as we know it. More importantly, it is at the nanoscale that matter becomes life. That's why debates about genetic engineering and the nature and origin of life must take the nanoscale into account. Our emerging power to sculpt the molecular foundation of all that we know is remarkable, but it is also frightening—and it will surely change our understanding both of the world and of our place within it.

So, although it may in fact be easier to imagine faraway galaxies or the time of the dinosaurs, it is at the nanoscale that we will learn about the scientific underpinnings of the material world that surrounds us and makes us who we are. As we begin to manipulate the basic properties of all materials, the boundaries between the natural and the technological will continue to blur. With the help of artists investigating the nanoscale foundations of the material world, we may build a broader appreciation not just of new materials but also of the poetics of the science of everyday objects and materials. In parallel, we will debate and digest new nanoscale understandings of life itself. As we create nanostructures that mimic living systems, we will generate and test new theories about the origins of life and the material foundation of consciousness. All of this should stir up great intellectual and cultural debate. It is here, alongside the scientists and philosophers, that I would like to see artists: raising new questions, discovering new aesthetics, and helping us orient ourselves in a yet-to-emerge intellectual and technological landscape.

Tom Rockwell is Associate Director for Program at the Exploratorium and co-Principal Investigator for the NISE Network.

Perspectives

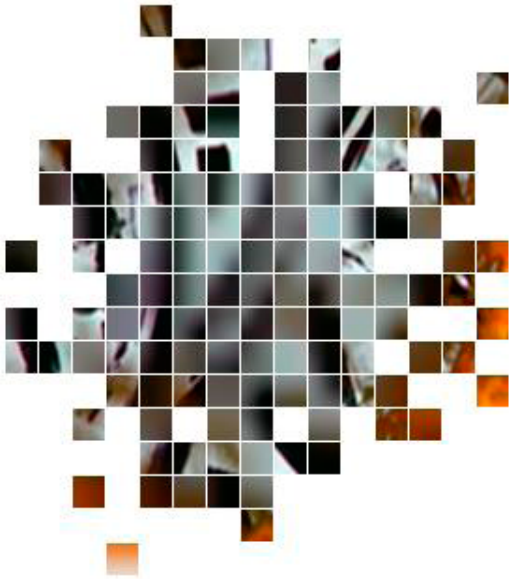
Pamela Winfrey

Creative Agar: The Exploratorium's Artist Residencies

Through an evolutionary process, a culture has emerged [at the Exploratorium] that nurtures playful investigation, experimentation, and a propensity for taking risks. - Peter Richards, Founder, Exploratorium Artist-in-Residence Program

I have worked with the Exploratorium's Artist-in-Residence program for twenty years. During that time, the museum has gathered artists to help us create numerous exhibits on a wide spectrum of scientific concepts, including genetics, navigation, light and color, sound, dynamics, culture, geometry, memory, sports, time, AIDS, water, and vibrations (just to name a few). We include artists in almost all of our activities, because artists–whether on staff or participating in invited residencies–add an essential voice to our investigations of the world around us. Science and art are two of many ways of looking at the world, and I have learned that the most iconic, expressive, and engaging exhibits are usually those that let the viewer see the world through both artistic and scientific lenses. With this dual viewpoint, a visitor can actually flip back and forth as with an optical illusion, to critically examine a subject from both perspectives. This combination of aesthetics, information, and direct experience often creates the most memorable and provocative results.

However, the success of an artist's residency is measured by more than the product left behind. In fact, many creative experiments, whether developed in the Exploratorium's machine shop or the artist's studio, never make it to the museum floor. It is the process, the dialogue engendered during the experiment, which is invaluable, because it often produces unexpected outcomes and innovative solutions to problems yet to be fully articulated. If I have learned anything during these years, it is that ideas are like a well filled with fresh spring water: they are constantly renewing, invigorating, and refreshing. When the relationship between the arts and sciences is symbiotic, the Exploratorium acts much like a catalyst in a chemical reaction, introducing the artist to scientific advisors and staff experts who in turn bring fresh ideas back to the museum. Quite literally, the Exploratorium is an institution fueled by such collaborations.



The importance of this concept of bringing the arts and sciences together to cultivate a creative environment cannot be overstated, and it manifests itself in unexpected and unpredictable outcomes. Here are a few examples:

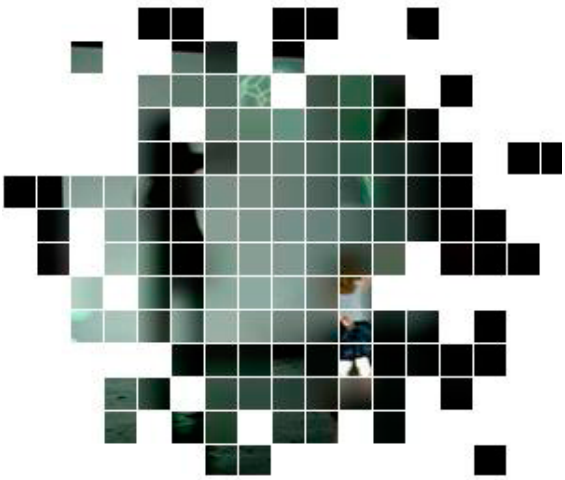
- A concert cellist from Australia, Sarah Hopkins was interested in experimenting with the corrugated plastic sound toys sometimes called "whirlies." In 1988, she met Exploratorium physicist and teacher Paul Doherty, who subsequently became deeply fascinated with these seemingly simple playthings. Together, they embarked on an intensive investigation of exactly what was going on when a whirling whirly made its humming music. Sarah left with a better understanding of her newfound concert instrument–and Paul created a full science curriculum based around it. For many years afterward, when Sarah came into town, she invited Paul to perform in her concerts. And to this day, a low thrumming sound can often be heard throughout the Exploratorium as Paul whirls a thirty-foot tube around his head, explaining the complicated physics behind this amazing sound. His interest was emotional as well as scientific: In one issue of the Exploratorium's quarterly magazine, he noted, "As Sarah played, tingles ran down my spine; her music recalled emotions that I have felt while sitting high in the mountains at night, listening to the wind wail through jumbled blocks of granite. I felt alone in the universe, but at peace." (For a

hilarious and instructive description of that project from Paul's perspective, please go to http://isaac.exploratorium.edu/~pauld/activities/AAAS/aaas2001.html.)

- In 2007, resident artist Kal Spelletich created a large mechanical sculpture called *Master Mind Machine* as part of the museum's new Mind collection devoted to helping visitors investigate thinking and feeling. I was struck by the positive impact Kal had on many of our other exhibit developers. He is an excellent problem solver, has an open personality, and is extremely knowledgeable about technical devices and building techniques. He has formed an especially tight and productive partnership with Ray Gruenig, an electrical engineer and one of our most experienced developers. These two have launched an exploration into human-machine interfaces, experimenting with the possibilities offered by EEGs, sweat-detecting devices, and other ways that people can interact with robots. The results of these unplanned explorations will surely be reflected in upcoming exhibits.

- Sound artist Trimpin visited us in 1990 on a mission to suspend a *gamelan*–an Indonesian percussion instrument–within a magnetic field. (The intent was to free the gamelan from its usual mount and let the undampened instrument resonate as fully as possible.) Trimpin worked with an Exploratorium engineer to explore new ways of making the project work, and together they refined a technique for using a magnetic field to float the top of a nitrogen tank. The engineer ultimately realized that what they'd learned together would help him redesign an existing exhibit and allow it to work better than it ever had before. As in all good partnerships, both parties got something out of the collaboration.

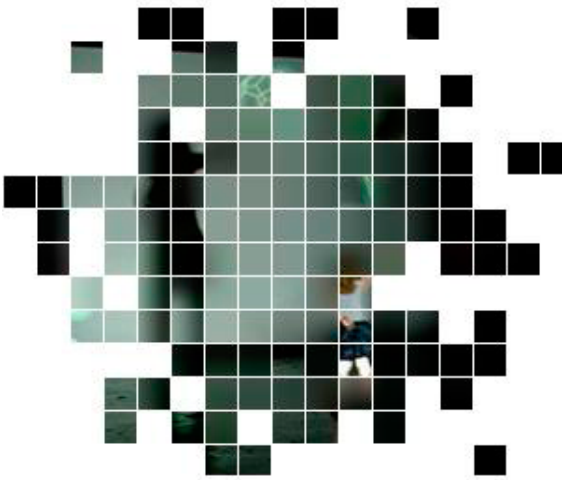
- Chico MacMurtrie was a young artist who came to the museum with energy, ideas, and passion, and he was ripe for new technical challenges. Dave Fleming, one of our technical experts in the machine shop, introduced Chico to pneumatics. This initial exposure to a relatively simple technology had a major impact on Chico's work and led to his becoming a major artist in the realm of large-scale mechanical sculptures.



The Process

It's clear that these and other collaborations have been fundamental to the creation of many unplanned and exciting works. But how do these residencies actually work? Initially, each opportunity is structured organically. Most of our larger exhibit-development projects (often funded by the National Science Foundation), such as our current project exploring nanoscale science, are driven by a diverse team of exhibit developers, scientists, and other staff. The team and I work together to determine a process for identifying and selecting artist(s). This process may include putting out a full-fledged call for proposals or making direct solicitations to individual artists. After receiving proposals and support materials, we work together to reduce the group to a manageable number, and we bring in local artists to present their work to the group. We may invite artists from out of the area for an "exploratory" residency, a one- or two-week opportunity for institution and artist to get to know each other. After we familiarize ourselves with each other, we're all in a better position to determine the most appropriate collaborations for creating an exhibition or display.

In general, once an artist is selected for a residency, one member of the project team (usually an experienced exhibit developer) is assigned to work directly with the artist. This person acts as a liaison, introducing the artist to the culture of the institution, helping to familiarize them with the procedures and traditions of the machine shop, and acting as a general technical consultant.



This open process insures that the artist has maximum exposure to the various working areas within the museum–and this is key, because I can never predict when or where a productive liaison will crop up. In fact, some of these relationships last a lifetime, the partnerships forged during the residencies taking on new life as the collaborators continue to work on new projects together. (Sometimes, because of a lack of facilities or scheduling conflicts, we have allowed the bulk of a residency to take place offsite. Although such situations can allow for the creation of a successful work of art, they tend to lack the powerful exchange of ideas which I have come to value as the hallmark of a successful residency, presumably because immersion within the Exploratorium culture is a core ingredient in that success.)

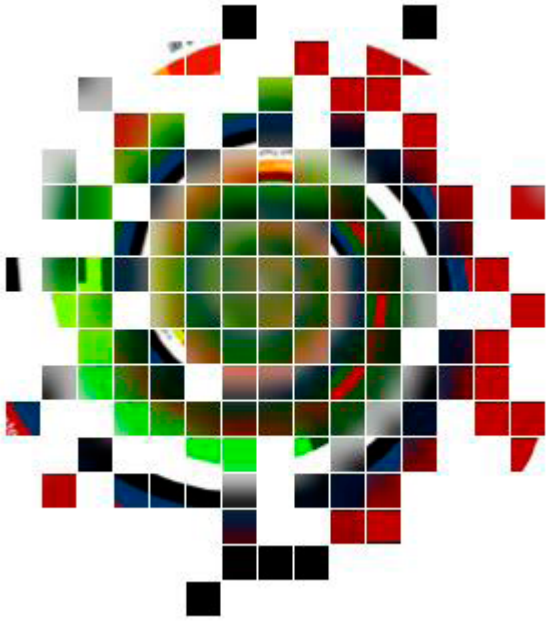
In truth, everyone at the Exploratorium benefits immeasurably from being able to work with visiting artists. I am particularly struck by the ability of artists to translate and make sense of our world. They bring fresh perspectives, innovative ways of problem solving, and an extraordinary sense of how to present difficult ideas to a diverse public. In fact, I think of them as a sampling of our public: interesting people interested in being exposed to interesting ideas. When a residency truly “flows,” an interdependent relationship is formed with both artists and institution reaping the benefits, both positively affected by this multidisciplinary discourse. I often refer to this invisible intellectual palette as the “creative agar” of the Exploratorium, a Petri dish brimming with unseen possibility, waiting for a new idea that will ignite the imaginations of both staff and visitors.

Pamela Winfrey is Senior Artist at the Exploratorium.

About

Background

ArtNano: New Approaches for Visualizing the Nanoscale



The nanoscale is so small that we can't really see it or experience it–so how do we describe it? One hundred thousand times smaller than the width of a human hair, the nanoscale is a world where incredibly small particles are governed by physical forces beyond our experience. The NISE Network's Visualization Laboratory at the Exploratorium is addressing the problem of describing the nanoscale by exploring effective and innovative ways visualizations can be used to understand and experience the very small.

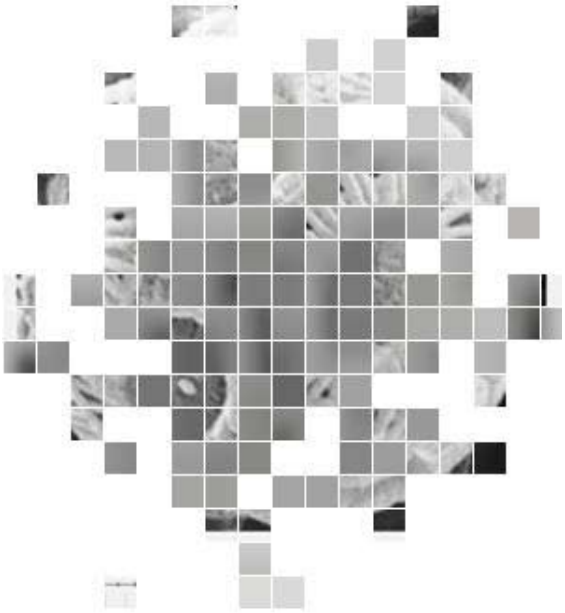
In 2006, the Visualization Laboratory invited several artists to participate in installations, commissions, and residencies that explored different approaches to visualizing the nanoscale. From the inception of the Laboratory, artists were identified as potentially rich explorers of this unfamiliar terrain. The resulting artworks and experiments are presented in this website. These projects identified new techniques, approaches, and challenges that have shaped the direction of the Visualization Laboratory's products and research. By documenting these projects, it is our hope that they can influence and inspire the work of others facing the challenge of portraying this remote landscape.

Jennifer Frazier, Project Director, Visualization Laboratory

About

NISE Network

Nanoscale Informal Science Education (NISE) Network

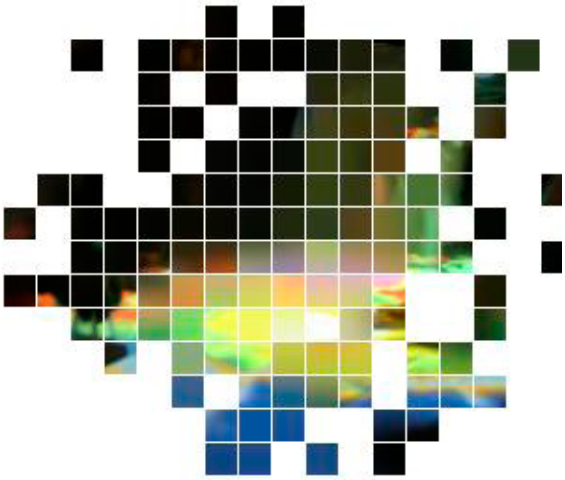


The Nanoscale Informal Science Education (NISE) Network is a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science and technology. The NISE Network is currently funded by a five-year cooperative agreement between the National Science Foundation, the Museum of Science, Boston, and the Museum's core partners: the Science Museum of Minnesota and the Exploratorium. The Network's goals are to: 1) support widespread efforts to raise public awareness of nanoscale science, engineering, and technology; 2) plan, develop, and distribute informal educational products that foster engagement with and understanding of nanoscale science, engineering, and technology; 3) form partnerships and working alliances with researchers in the field to carry out this work; and 4) stimulate and support research aimed at increasing our capacity to meet these goals.

http://www.nisenet.org/

About

The Exploratorium



The Exploratorium

History

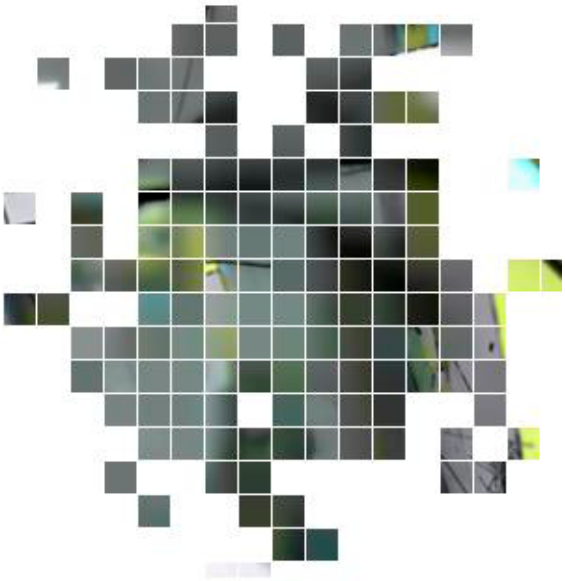
Housed within the walls of San Francisco's landmark Palace of Fine Arts, the Exploratorium is a museum of hundreds of interactive exhibits that let visitors investigate science, art, and human perception. The Exploratorium stands in the vanguard of the movement of the "museum as educational center." It provides access to, and information about, science, nature, art, and technology.

This unique museum was founded in 1969 by noted physicist and educator Dr. Frank Oppenheimer, who was its Director until his death in 1985. From 1991 until 2005, the museum was led by renowned scientist and educator Dr. Goéry Delacôte. In May 2006, nationally-known science education and policy expert Dr. Dennis M. Bartels was named Executive Director.

http://www.exploratorium.edu/

About

Staff Biographies



Jennifer Frazier
Project Director, Visualization Laboratory

Jennifer Frazier arrived at the Exploratorium in 2004 to develop exhibits and multimedia for the museum's Microscope Imaging Station and *Traits of Life* collection. Before joining the Exploratorium, she created exhibits, multimedia, and documentary films at NOVA, the National Academy of Sciences, The Tech Museum of Innovation, and several multimedia companies. Jennifer received her PhD in cell biology from UCSF, where, as an NSF and AAAS Fellow, she used advanced imaging techniques to study polymer assembly during cell division. She has a BS in bioethics and genetics from the University of California, Davis.

Tom Rockwell
Associate Director for Program, Exploratorium

Visual arts training and a lifelong interest in combining art and science led Tom to work first as a science museum educator at The Franklin Institute and the Academy of Natural Sciences in Philadelphia, and then as a designer and construction coordinator of community-built science parks and playgrounds with Leathers and Associates in Ithaca, New York. In 1995, Tom founded Painted Universe, Inc. to pursue exhibit design, fabrication, and scientific illustration. Painted Universe's projects included exhibits for the Materials Research Society; traveling exhibitions, such as *It's a Nano World* and *Too Small To See* (with the Ithaca Sciencenter and Cornell University); *The Enchanted Museum: Exploring the Science of Art* (with the Berkshire Museum); and illustrations for *The Elegant Universe* by Brian Greene. In 2005, Tom joined the Exploratorium and is currently a Principal Investigator on the National Science Foundation-supported *Geometry Playground*, and Co-Principal Investigator on several projects, including the Nanoscale Informal Science Education (NISE) Network.

Pam Winfrey
Senior Artist, Exploratorium

Pamela Winfrey joined the Exploratorium in 1979. Recent exhibitions curated by Winfrey include *Virtual Unreality* (2007), *Liminality* (2007), *Reconsidered Materials* (2006), and *Art Life* (2004), an exploration of artworks with human and living attributes. In celebration of the fifth anniversary of Irvine, California's Bealle Center, she curated *Five*, an exhibition that featured five interactive media artists from different countries. She has served as a panelist for Ars Electronica (Linz, Austria) in the interactive arts category. In 2007, she was the lead curatorial consultant for Creative Capital's emerging art forms.

Ms. Winfrey is a playwright and performer. She was a founding member of Mobius Operandi, an electro-acoustic sound sculpture ensemble. During her tenure with the company, they produced two CDs and five large-scale performances. *The Sounding*, Winfrey's drama based on the laying of the Atlantic cable, was read at *Science on Stage 2004* at the Magic Theatre. Plays and performance works by Winfrey have been presented at numerous venues around the country. She received a Marin Arts Council Independent Artist Award and a Sloan grant for *Celestial Bodies*, a play about the first female radio astronomer. She has also received awards from both the Marin Arts Council and NJNG Productions in New York for a new recording of an untitled musical that she is writing with Christie Winn.

About

Credits

We extend special thanks to all of the artists and scientists who contributed to this website, and to members of the Exploratorium staff who assisted in the production of the artists' residencies.

In addition, we would like to acknowledge the participation of the following individuals:

David Beck, Producer, nisenet.org

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Susan Miller, Website Production Manager

Josh Myers, Exhibit Developer

Tom Rockwell, Associate Director for Program

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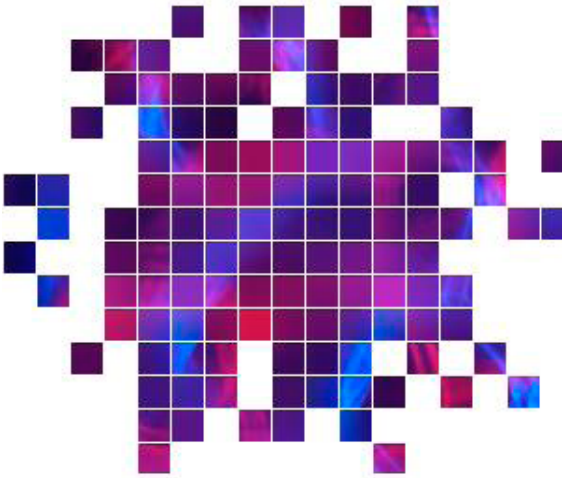
Pamela Winfrey, Senior Artist

Dan Zevin, Senior Project Manager, Visualization Laboratory

For questions or comments about this website, please contact artnano@nisenet.org.



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