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Mathematical Connections
in Art, Music, and Science

Whirling Chaos: A Multisensory Kinetic Art System

Joe Cusumano
Department of Engineering Science & Mechanics
Penn State University
University Park, PA 16802, USA
Email: jpc@crash.esm.psu.edu

Abstract

A kinetic *art system* that recontextualizes a scientific experiment into a museum/gallery environment is described. Phenomenologically, the sculptural installation deals with instability and chaos in the nonlinear dynamics of a whirling flexible rod. The complete interactive system consists of a mechanical kinetic sculpture with integrated electromechanical excitation, sensors, signal conditioning and audio special effects electronics, speakers, digital oscilloscope, and a video projection subsystem. In simple didactic terms, the sculpture serves as large-scale system for experiencing nonlinear dynamical phenomena in a direct, playful way that engages the senses. More fundamentally, this art system raises questions about the process of data abstraction and transformation, important in science both as an extension to our natural senses as a source of new theoretical ideas.

If there had been no poets there would have been no problems, for surely the unlettered scientist of to-day would never have found them. To him it is easier to solve a difficulty than to feel it.

—Gregory Bateson

Initial Conditions

Two summers ago, I spent six weeks visiting and working at San Francisco's Exploratorium, which rightly views itself as a museum of "Science, Art, and Human Perception," but which, I suspect, is viewed by most visitors as a "hands-on science museum." My experiences there, as well as at other similar institutions, have furnished me with many powerful examples of how far science museums have come in the last quarter of this century.

The most obvious change in these museums, and perhaps the most fundamental, is the shift towards the "hands-on" or interactive model itself. This shift is profound because it signals a move into the public sphere of a radically democratic theory of knowledge. At museums that employ such a model in its purest form (such as the Exploratorium), one will see a minimum of placards telling visitors what an exhibit is "about." Rather, the emphasis is on personal exploration. The design of exhibits, and of the museums themselves, encourage and enable a viewer to construct knowledge for themselves.

The relatively nonhierarchical notion of knowledge implicit in such a museum gives subjective experience a prominent role. Yet, at the same time, it is strongly dependant on a scientistic-humanistic belief system which takes the existence of an objective reality *outside* of the individual as its starting point.[1] It is precisely the faith in the existence of such an objective reality, however mediated it may be by subjective experience, that gives the designers of the new science museum the confidence necessary to let the visitor, to a large extent, find their own way.

The existence of such museums represents the scientific ethos at its best—the same ethos which, for example, has recently spawned the internet, progressive hacker culture, and the "open source" movement.[2] Of course, since I am an academic scientist, the pride implied by this statement is unavoidably tainted by vanity, and certainly deserves a more critical treatment than is possible in this brief paper—nevertheless, perhaps the clearest illustration of this view can be obtained by reflecting upon the experience of visiting this new breed of science and technology museum, and comparing it to that of visiting a traditional art museum.

At an art museum, an exhibit on, say, Abstract Expressionism will almost always be accompanied by an official introduction telling us why it is important and what it all means. In the theory of knowledge implied by this expert framing of an exhibit or show, the cultural gatekeepers (art historians, curators, critical theorists, and to some extent the artists themselves) signal their presence and play a decisive role, a role which has unfortunately left many people alienated from art, as something they are not qualified to understand. More significantly, it is inconceivable that visitors to an art museum would be encouraged, for example, to impart motion to a Calder mobile, or participate in the making of, say, a drip painting in the style of Jackson Pollock. The perceived preciousness of art objects, the "star system" of the art marketplace, and its emphasis on the "genius" of the lone artist: all of these things inhibit the traditional art museum from allowing visitors to discover for themselves some of the truths pursued by the artists.

In contrast, the participatory objectivity at the heart of hands-on science exhibits has not only lead to increased interaction between lay people and the stuff of science, but has also stimulated collaboration between artists and scientists, and is helping to bring into the foreground the long-neglected subjective aspects of science and technology making. At the very least this is a practical matter: in a public education setting, which is what a museum is, artistic means are necessary in exhibit design in order to convey complex, abstract or subtle ideas to a general audience. In information-theoretic terms, the incorporation of artistic elements is required to increase the "bandwidth" of the exhibit without recourse to high level formal languages available only to those with extensive training (in, say, mathematics and physics).

The issues raised by this emerging participatory trend in science and technology museums, and the demands it places on exhibit design, formed a significant component of the motivation for the work presented here. The "art system" described in the next section is part of an ongoing research project which developed as an outgrowth of rather free form explorations at the Exploratorium, the central aim of which was to integrate artistic and scientific modes of working in order to develop a publicly accessible, interactive presentation related to nonlinear dynamics. In a very real sense, this work is an experiment in communication: I am trying to find forms of presentation which go beyond merely presenting the basic *facts* of dynamical systems theory. I am interested in conveying certain abstract notions from nonlinear dynamics (such as *phase space*, *behavioral multiplicity*, *instability*, and, of course, *chaos*), but I want to do so in in a visceral and intuitive way for a general audience.

[1] This is true even in the evolving postmodern scientific/technological worldview, in which a strict classical Cartesian dualism does not necessary hold sway.

[2] It is in this regard not a coincidence that the Exploratorium was founded by physicist Frank Oppenheimer, the brother of Robert Oppenheimer.

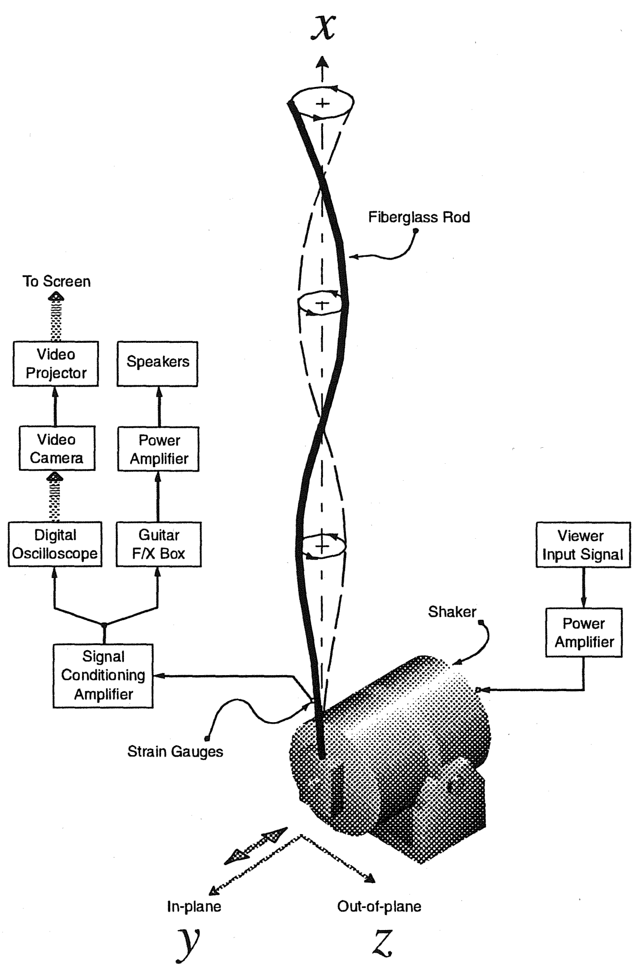

Figure 1: A schematic of the Whirling Chaos system architecture. The viewer input can come from a variety of sources, or be replaced by an autonomous signal source. See text for further discussion.

System Description

The system considered here is a sculptural installation with mechanical, audio, and video kinetic elements. For ease of discussion, I will refer to it as "the Whirling Chaos system", or simply "Whirling Chaos"—though it is an evolving concept with has had different names at different times.

Whirling Chaos is an *art system*, by which I mean to emphasize several of its key features. First, the work is essentially conceptual in that its meaning is to be found in the interrelationships between its various parts: it is not an art object in the usual sense. Second, given this conceptual nature, no one physical realization of the system is "the piece:" the system has had various incarnations. However, all of the installations that have been carried out as part of this research project have had the same basic thematic elements (e.g., same or similar physics, and integration between mechanics, audio and video), but were each executed for a different site, with an evolving understanding of the system's capabilities, and with different equipment and time constraints. This distinction between *system* and *realization* is common in systems theory, and leads us to the final reason for using the notion of art system: the work presented here was carried out using a process that has more to do with that of the scientific or engineering research group than with the traditional craft-oriented artist's process.

The central component of Whirling Chaos is a thin, flexible fiberglass rod (nominally 1/4 inch diameter by 7 feet tall) which is shaken at its base in a vertical (x-y) plane (See Figure 1 for a schematic diagram). According to linear vibration theory, given the symmetry of the rod and forcing, the motions would be expected to stay in the x-y plane, however symmetry-breaking instabilities (*bifurcations*) occur near the in-plane natural frequencies of the rod which give rise to visually interesting and beautiful quasiperiodic and chaotic modulations, during which the rod pulsates and "dances" as energy is exchanged between clockwise and counter clockwise whirling motions.

Simultaneous with these events, live video is projected showing a two-dimensional projection of the rod's motion in phase space, obtained with y-z strain gauges at the rod's base. At the present time, we have achieved the best (affordable and controllable) video effects by shooting the y-z trace directly off of a hooded oscilloscope. By controlling shutter speeds and f-stops on the camera, and using available in-camera effects, a variety of different appearances can be given to the projected image. The strain gauge output is also run through a guitar special effects box and power amplifier to create an ambient sonic environment. Since the fundamental frequency of the system as typically operated (approximately 13 Hz) is well below audible frequencies, subwoofers are desirable. Depending on the mix of dry (pre-effects) and wet (post-effects) signals, the audio portion of the system can be made more or less audible: with sufficient speaker power this allows for different mixes between audible sound and inaudible "sound" perceivable through body feel only. By using stereo separation and/or different effects for y and z channels, a counterpoint between two speakers can be used to provide an audio analogue for the what the viewer is seeing as the rod whirls in and out of the the x-y and x-z planes.

The input to the system is provided by a controllable signal generator. Using a suitable user interface (as discussed in more detail in the next section), the entire installation allows the viewer to explore the system in a way that engages the human sensorium through sight, sound, and touch.

Phenomena and Variations

For strictly sinusoidal forcing, the rod is observed to pass through three distinct dynamical regimes as the driving frequency and amplitude are tuned: planar periodic oscillations; whirling quasiperiodic and chaotic oscillations; and periodic ballooning motions. We have recently been studying the system experimentally in some detail[3], and have found that the whirling region has a beautiful fine structure in which bands of chaos and quasiperiodicity are interwoven. The basic expression of the behavior in the whirling regime is that the forcing frequency becomes *modulated*, either periodically (for quasiperiodic whirling) or chaotically (for chaotic whirling). Since this is primarily a resonance phenomenon, this general state of affairs is repeated near each natural frequency of the system.

The modulation gives rise to distinctive sound patterns which fade in an out (and from location

[3]That the system can be treated as an experimental system for legitimate scientific research as well as an art system or museum exhibit is another important aspect of its design.

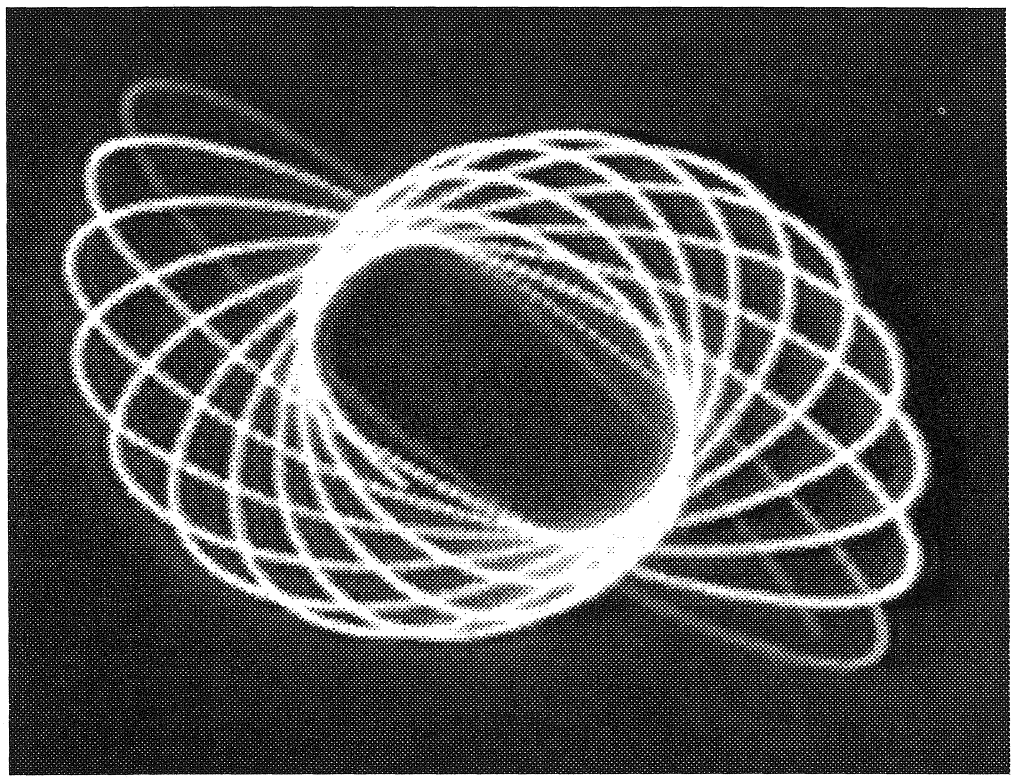

Figure 2: A frame from a typical "representational" video projection of the rod when it is in the whirling regime.

to location, if multiple speakers are used) as the motions move in and out of plane. Visually, the modulations correspond to characteristic continuously-evolving spiral patterns in the video.[4] In Figure 2, an image from a typical video projection in the whirling regime is shown: for this particular video, the oscilloscope sampling rate and video camera shutter speed are set to give a "representational" image of the phase plane plot on the oscilloscope screen. This type of setup is suitable for a more didactic, museum-oriented installation. More evocative, abstract representations can be achieved with different settings, however, unfortunately, these do not translate well into print.

Given the general architecture shown in Figure 1, a variety of installations are possible. The simplest interactive installation uses a dial or knob to control the frequency of a sine wave from a signal generator which is used to drive the shaker. In this type of installation, the system functions like a large scale experimental system with only one control knob. This avoids burdening the viewer with extraneous switches, knobs, dials, and their associated markings, and allows them to contemplate the phenomenon before them. For the same reason, the axes have been removed from the oscilloscope trace projected onto the screen. An installation of this type is shown in Figure 3.

In another installation, people in a San Francisco convention center were able to use a signal generator to control the system as installed on the Penn State campus. The signal was sent over the internet by putting it into the audio port of a streaming video encoder. Live audio, and video of the rod tip, (see Figure 4) was sent out to San Francisco, again using streaming video. The

[4]Note that these *are not* Lissajous patterns, since they do not repeat.

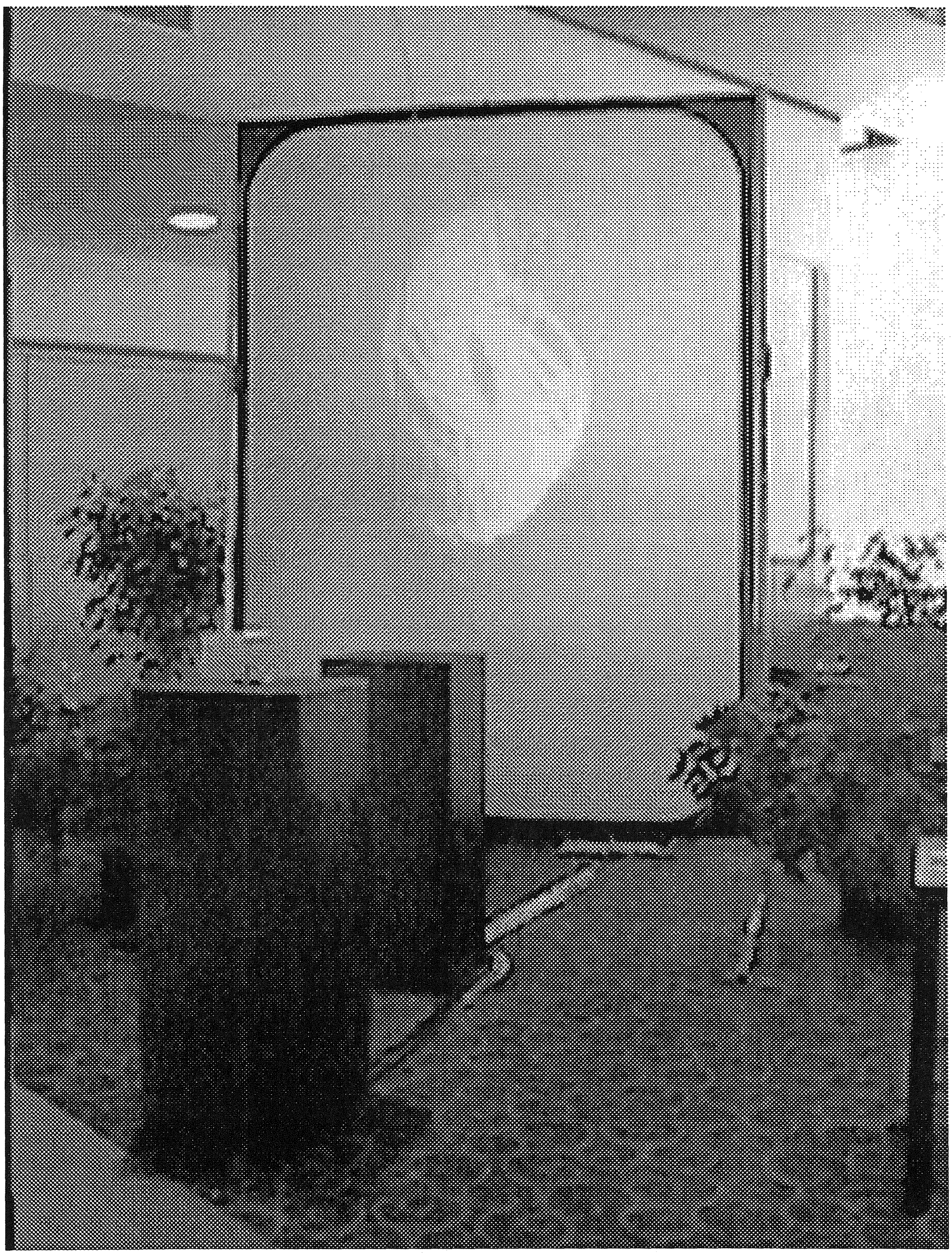

Figure 3: A recent installation of the Whirling Chaos system. The pedestal in the front contains a simple dial interface that varies the driving frequency of the shaker. The rod emerges from the second pedestal, which contains the shaker. Audio and video subsystems, and electronics, are all behind the screen.

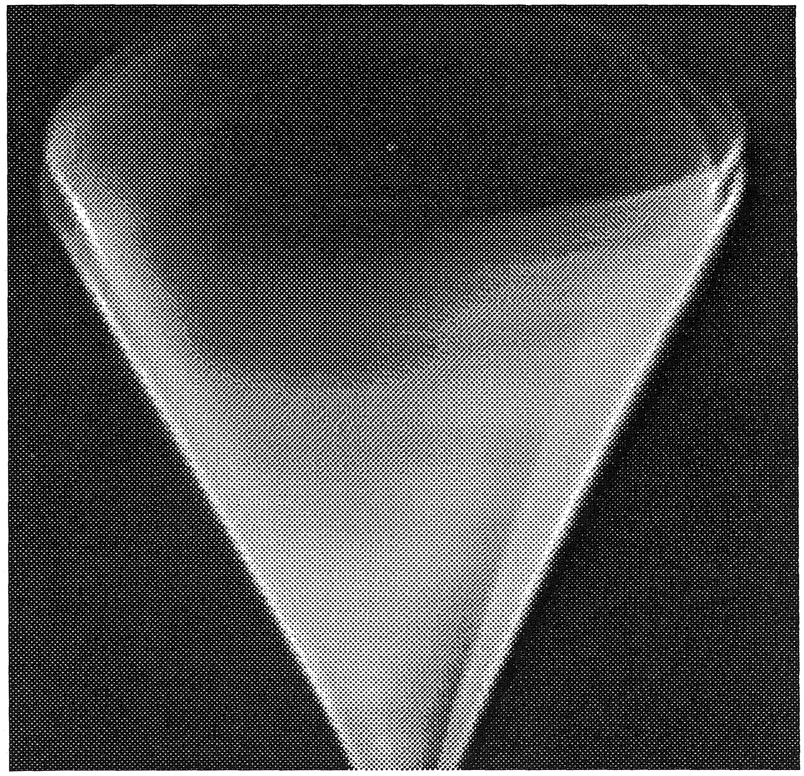

Figure 4: A frame from an alternative "representational" video projection of the rod tip. Note the use of a relatively low shutter speed to obtain the motion blur effect.

entire event was used as an interactive demonstration of I2 (Internet 2) technology.

Current research efforts for the system are focusing on improving the user interface, to make it more richly controllable, as well as more durable. To accomplish this, I would like to see the system depend less on direct mechanical manipulation by the observer and function more by responding to the environment through non-contacting sensor inputs. For example, an ultrasonic motion detector has been used to provide input to the rod based on the velocity of hand motions in front of the sensor.

The Current State

From the point of view of public art, one way to think of design experiments like Whirling Chaos is that they attempt to provide a glimpse into the mind and heart of the scientist. That is to say, art systems can be used to furnish a representation of the scientific and technological work process that includes not only its important analytical and reductionist aspects, and not only the objects of its inquiry, but also its sensual, poetic and esthetic dimensions.

By representing these latter subjective components of the scientific world view—by, as it were, reclaiming them for science—a humanistic description of science and technology that speaks to the intentionality of the practitioner can be developed that is more than merely utilitarian or instrumentalist.

Thematically, the process of data transformation and abstraction so critical to the scientific enterprise, is implicit in such installations. In addition to experiencing a wide range of phenomena possible in nature, the viewer can gain some understanding of the way in which scientists use abstract ideas both as an extension to our natural senses and to develop new theories about the world.

Acknowledgements

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