

Learning Chaos in an Interactive Virtual Museum

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Abstract— This paper describes a virtual museum which introduces the interactive VR and MEMS applications related to the learning of chaos and complexity theories. In this museum, the user can learn the history of the dynamical systems and build the Chua's circuit, connecting it to an interactive screen in order to visualize chaotic behavior, and changing the systems parameters. Thus he/she will realize artistic artifacts, transforming attractors into sounds and music. Regarding the educational path, we carried out an experimentation with students of different school rankings. Then, we used these emotional- driven activities to implement the Virtual Museum of Chua's Attractors, also with the aim to widen the experimentation by the net. The paper presents a description of the virtual museum architecture and a detailed explanation of its applications.

Index Terms—Chaos, Virtual learning technologies, Science dissemination.

I. INTRODUCTION

The advantages of integrating technologies in educational environments have been widely discussed in literature [1, 2]. Nowadays, Virtual Reality allows the creation of multimodal and multi-activities environments for science education, by which the user can have an active role exploring the contents and learning by doing or playing. Hence, the virtual space is not only a tool for representation, but also a tool for action and interaction, integrating constructivist theories as well [3]. Many authors suggest that the interaction with virtual environments and immersive 3D scenes involves learning, but not all the environments imply education [4, 5]. The users can learn and improve their skills because the interaction mechanisms strongly stimulate cognitive capacities such as eye-hand coordination and visual-spatial representations.

Virtual environments could be used to present and disseminate many scientific topics [6]. Moreover, auditory display techniques combined with immersive virtual environment could be used both to improve the comprehension of scientific phenomena by using 3D modeling and music, and to use science for artistic purposes [7]. Many authors suggest that digital learning application can stimulate students' interest about complex scientific topics. The students' lack of interest into scientific topics originates from the difficulty to understand specific phenomena. However, the 3D visualization of scientific objects, associated with real-time interaction, and the simplification of the complex

phenomena can involve students. Moreover, by providing various interactive hands-on paths, it is possible to engage them in an immersive learning environment on topics like physics and mathematics. Furthermore, since the pioneering experiments in hands-on approach of Museums such as La Villette, Paris, The Exploratorium, San Francisco (just to cite a few), a Virtual Museum has become a compelling metaphor by which it is possible to create high scaffolding educational environments.

The aim of this paper is to present a Virtual Museum in which visual and auditory representations of three dimensional chaotic and complex objects show the simplicity of science learning. This tool has not been designed for advanced users and is an easy-to-use, easy-to learn, and stand-alone environment. In particular, we present the user's interaction we have planned in order to advance her/his capability to understand chaos and complexity.

The paper has 5 sections: Section 2 introduces science dissemination and the use of new technologies. Section 3 presents the main scientific topics displayed in the Virtual Museum. Section 4 deals about the virtual environment with a detailed description of the interaction systems we have developed. Section 5 concludes the paper providing future directions of this work.

II. SCIENCE DISSEMINATION AND NEW TECHNOLOGIES

Science learning could be also a creative activity which can also involve the students' emotional-cognitive side if they are rightly motivated to develop scientific and creative artifacts by using different multimedia tools as images, sound and music. We think that it is essential to transmit this message to young generations in order to involve them into scientific studies. Traditionally, in formal context, such activity needs to be learnt in a rigorous way, missing the creative side of science which is instead experienced by scientist [8]. Museum and science centre are becoming places where a strongly interaction among scientific research, art, creativity and applications of new technologies are increasingly developed. A wide number of interactive exhibits are incorporated into galleries in order to enhance the visitors' experience [9, 10]. Frequently museums present exhibitions developed to facilitate new forms of participation in science, and often attempt to communicate science in novel ways to the public. Many museums in the world exploit the new media potential

and offer concrete opportunities for learning and education.

Basic research and science communication are very crucial and important aspects for progress and development. The lack of interest in key science topics and mathematics has been linked to the way they are taught from the earliest age. Therefore, greater emphasis needs to be placed on the development of more effective forms of learning method, and analytical skills as well as the improvement of techniques for stimulating intrinsic motivation for learning science. Many researches show that learning by non traditional methods is a successful experience. Research in Psychology indicates that active learning (the physical construction of knowledge by using the hands in coordination with the eyes) could remarkably enhance students' learning efficiency [11]. A rich interaction can offer participant feelings and, hence, benefit students' active learning, and promote teaching effects. An immersive environment allows a direct approach to science, influencing the formation of critical thought, the development of psychological and social relationship, scaffolding the learning process. The users are active subjects in the virtual environment and learn by performing different activities. On the side of the system development, the construction of *the Virtual Museum of Chua's Attractors* has been an interdisciplinary effort and many problems of attractors representation in graphics have been already solved [12], but a lot of work needs to be done. Due to the difficulty of chaos visualization, the quality of the interaction with dynamical systems that it is possible to realize and the development of compelling paths on complexity and chaos is still at the beginning. We want to exploit the cognitive advantages of learning by a virtual museum in an immersive audio-visual three-dimensional scene. The complexity of many physical phenomena can't be easily understood, this is even at the base of the chaos basilar mythological concept developed by the ancient Greeks. Contemporary science tried to understand the principles of chaos theory. In particular, Chua [13] invented the first circuit able to visualize chaos. In the following 30 years of research on this topic, many studies have experimentally, mathematically and physically demonstrated chaos. This effort changed the way we perceive science and the scientific discoveries in society, developing larger and more complex visions of the phenomena. Basically the aim of research is to open a new access to science matter for everybody and not only for scientists. In this view, the Virtual Museum we have developed try to activate a new way of learning science, linking our everyday life to scientific improvements. The museum promotes also collaborative and social skills, based on shared learning and joint activities among students.

III. CHAOS AND COMPLEXITY

Chaos and Complexity theories are some of the most remarkable achievements of science in the 20th century. A

complex system is a collection of many simple nonlinear units that operate in parallel and interact locally producing an emergent behavior.

A complex dynamical system evolves in the space of phases (the set of variables that define the state of the system) delineating a particular evolution. In Chaos Theory, we consider non-linear dynamical systems that evolve in an unpredictable behavior from initial conditions, even though their behavior is deterministic and well structured. Chaotic systems exhibit both complex behavior and stable dynamics in a well defined region of space known as "attractor".

Chaotic attractors themselves are markedly patterned, often having elegant, fixed geometric structures, despite the fact that the trajectories moving within them appear unpredictable. The geometric shapes of the chaotic attractors are the order underlying the apparent chaos. Chua's oscillator [14, 15] is a canonical system for research in chaos, since it can be realized in a real world setting as a simple electronic circuit. It is the simplest electronic circuit in which the presence of chaos has been proved mathematically. The circuit exhibits a rich variety of bifurcations and chaos and it has become a paradigm for chaos theory [16, 17, 18, 19]. For these reasons Chua's Oscillator and its mathematical model can be used in many different tasks such as research on non-linear dynamics and chaos, chaos theory demonstration, and also for educational purposes and science dissemination. The Lorenz attractor generates only few classes of dynamics and their associated patterns [20]. On the contrary, Chua's circuit, and all the systems based on the circuit, produces a broad variety of chaotic structures, of many different shapes and sizes [21]. Today more than one thousand attractors have been visualized [22-26]. The variety and richness of the chaotic shapes produced by Chua's circuit and its generalizations inspired the idea of creating a Gallery to collect them. The Gallery shows the complexity and the beauty of the chaotic patterns and presents science through an artistic interpretation. Simulation of chaos produces not only a wide variety of three dimensional model of attractors but also rich collection of sounds and music [27].

IV. EDUCATIONAL VIRTUAL MUSEUM

The virtual museum software architecture is as simple as powerful.

There are only three different layers: one for handling user interface, one for managing scenes, and one for 3D Audio and 3D Video render (simply called Render Engine). The user interface layer can receive and manage the inputs provided by different user controllers as Wii-mote, mouse and keyboard. Then the processed input signals are control by the scene manager that updates the user's avatar position and the point of view.

The scene manager also sends requests to render engine for drawing the virtual 3D world and playing sounds and music from exposed objects. The main employed technologies (Fig. 1) comes from free and open source projects: users' inputs are managed and filtered by

GlovePIE [28] and then translated in a compatible way for the user interface layer. The Scene Manager and 3D video Render are guided by Irrlicht [29]. The 3D audio rendering are controlled by OpenAL [30]. 3D Objects, Musics and Sounds enjoyable in the virtual museum, are generated at run-time in a systematic way, or randomly.

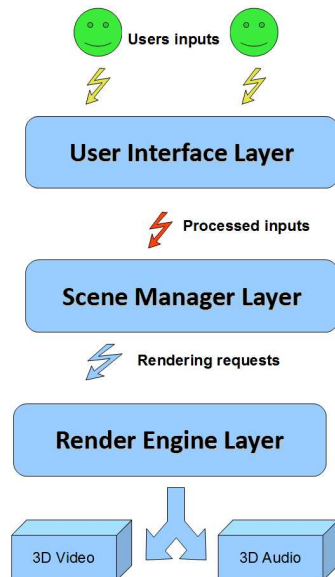


Figure 1. Architecture.

The Gallery of Chua attractors has become a virtual museum available both to researchers and to non specialists. Within the museum, visitors can manipulate the chaotic shapes, change their parameter values, create new attractors and listen to music and sounds generated by their dynamics. In this way, users can discover new and unexpected dimensions of chaos, beyond anything they could previously imagine.

Visitors to the museum are accompanied by an avatar that acts as a guide. It describes the general characteristics of Chua systems and their generalizations (including formal aspects) together with the characteristics of the specific system the visitor is looking at. The system allows visitors not just to admire the shapes but to manipulate them in a 3D environment, using special glasses for stereoscopic vision of the shapes and data gloves for interacting with the pattern in an unconventional way. This kind of immersive interaction with an artificial world provides visitors with an insight into the full complexity of chaos. The investigation of chaotic domain still requires much work. Nonetheless, there can be little doubt that the approaches and technologies we have developed provide new ways of exploring chaos, and expanding our scientific knowledge.

A. Interface

The main goal of the virtual Museum of Chaos is make use of science in a creative approach and arouse curiosity and interest of a wide auditory about chaotic phenomena. The virtual Museum tries to realize a concrete idea of edutainment tool that combines the educational and

entertainment purposes. The setting consists of a single navigable area divided by panels showing pictures of attractors and chaotic evolution. The visitor can control his/her position by using the general map of museum, located on the right bottom site of the screen. The museum symbolically contains five sections, like five different typologies of artistic productions coming out from chaotic system simulations. An avatar functions as guide in the space exploration (Fig. 2).



Figure 2. The avatar that accompanies visitors in the exploration of the Virtual Museum of Chua's Attractors. In the original idea of this character, the avatar is Professor Leon Chua who shows the different patterns of chaos to the visitors.

Moreover he can interact with three dimensional chaotic objects. Models of attractors in rotation are placed in central position and utter their characteristic sound.

The first section is dedicated to the attractors produced by the Chua's Oscillator. The second section is dedicated to present visual representation of patterns generated by the system with dimensionless equations. Other sections display images from the cubic functions and single point of equilibrium systems. The central parts of the Museum are dedicated to n-scroll, hyper chaotic and synchronized system. Many rotating attractors are in the middle of each room, like sculptures. The user can listen to sounds when he comes up to attractors. Special cameras, mounted on the sculptures, provide alternative views of the museum, directly under the user's control. The novelty bring into the last issue of Museum is a more user friendly interface and a new interaction system MEMS technology based.

B. Interaction system

Moving round the museum, the avatar (and the user) can interact with attractors, listen to music and sounds produced. The environment supports other forms of interaction. By controlling the avatar users can move from room to room interacting with the objects they find there. Moreover he can visualize, modify and hear the evolution of chaotic trajectory. But the success of such virtual "direct experience" depends heavily on the design

of interface and interaction techniques. For these reasons, the interaction between users and the immersive environment has been realized by



Figure 3. An user interacting with the environment by using a Wii Remote control by Nintendo Entertainment System.

an interface more usable and receptive to the user's needs, taking in account the experimentation we have done in a real class situation [31]. Since natural gestures can improve the efficiency of the interaction between the learner and the interface for exploring chaotic shapes, we choose to use a Wii Remote control by Nintendo Entertainment System (Figs 3 and 4).

We organized the museum like an immersive 3D environment that links pedagogical issues with game elements. The real-time interaction permit to explore scientific topic usually dedicated to specialists in an original fashion. The museum space contains a many of components, and each encapsulates specific areas: sculpture of attractors, painting and agent-based interface. Understanding the relationship between educational needs and environment elements will allow us to develop the improvement of this educational museum.



Figure 4. By using the Wii Remote control, the user can easily direct the avatar and interact with the systems visualized in the Gallery.

This tool could provide sufficient motivation to engage learners in knowledge discovery, while at the same time it develops new skills.

C. Applications

In the Virtual Museum of Chua's Attractors we have implemented 4 main sections, which correspond to 4 different types of interaction. In the first the user acquires knowledge on the main concepts related to chaos and complexity theories, by some short video that have been realized for making simple difficult concepts.

In the second section, more action-oriented, the user reconstructs the Chua's circuit in 20 steps, by interacting in a 3D environment by using a computer screen in a room in which other people are making the same activity. The construction is visualized in a wide shared 3D screen, and it is possible to use the single user's interaction or the shared users' interaction. Third and fourth sections are about the visualization of pattern generated by chaos and the realization of sound and music by using Chua's attractors.

The first section is related to stories on the Chua's circuit. On a wide 3D screen, which enables stereoscopic vision, the history of the Chua's circuit has been reconstructed in a film, which uses 3D VR and mixed VR technologies. User can view the film and observe the 3D patterns in stereoscopic vision to detect uncovered particulars of these shapes. Furthermore he/she can operate to review the main stream of the story. A movie of this section has been devoted to the relationship among dynamical systems, human creativity and arts, especially visual arts [32]. The educational aim of this section is to give some preliminary concepts about chaos, dynamical systems, creativity and science, how it is possible to detect the beauty in these mathematical patterns and transform them into sound and music.

The second section has an application which allows the Chua's circuit construction. Users are in a room in which they are connected to the 3D screen by a computer. First they watch at a 3D short movie which illustrates in 20 steps how it is possible to connect the circuit elements for allowing the system's working. Then they have to build the circuit by themselves both in real and virtual environment. Again the activity could be done by a single user or by many users together.

This method is based on the idea that the manipulation experience can be very effective in this context. Physical construction of the electronic circuit can stimulate the creativity and curiosity of the students, covering step by step the assembly of circuit components. The image in Fig. 5 shows "The Chua's Circuit Virtual Builder". The arrows in the down corners of the screen allow real time user's interaction which consent the users to navigate through the different steps of the circuit building. The construction of the circuit, as shown in Fig. 6, has been again transposed in a virtual application to let the students to experience and learn all different steps.

The third and fourth applications in the third section of the *Virtual Museum of Chua's Attractors* allows the modification of the 3D models of the attractors with a

real time interaction by controlling the system parameters.

Driving the MEMS interaction tool, students can experiment the modification of chaotic attractors and hear the acoustic signal produced by themselves.

As is possible to see in Fig. 7, a specific mask, shaped like a star, appears on the screen allowing the user to have a visual feedback of the change applied on the values of the parameters. The system allows also a multiuser interaction in the virtual experience on chaotic system understanding, like shown in Fig. 8.

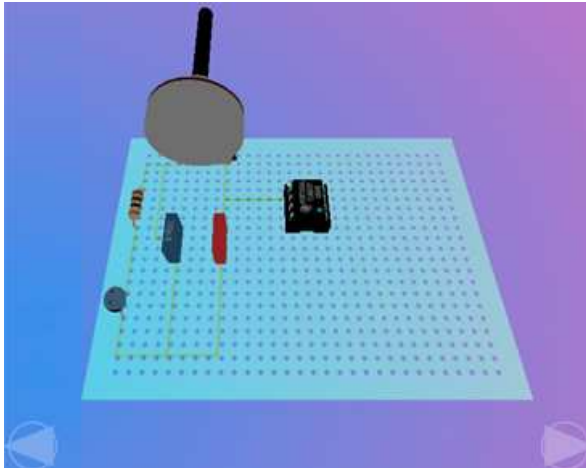


Figure 5. Chua's circuit virtual builder



Figure 6. Construction of the Chua's circuit

The developed system allows the user creating music and sound from chaotic shapes.

The mathematical models used in this environment are the dimensionless equations for Chua's Oscillator. These models, as the other generalizations of Chua's circuit, generate the sequence of numbers used to produce sound and music. Alternatively to the above mentioned interaction, a learner can use a MIDI Input Device that makes possible to change both the control parameters and the initial values, in order to obtain different kinds of sound and music. This process is very important for grasping the intrinsic nature of chaos as these variables are related to the sensibility to initial conditions of chaotic behavior. Furthermore, many translation codes have been developed, which allow a new way of understanding and studying chaos and complexity [33].

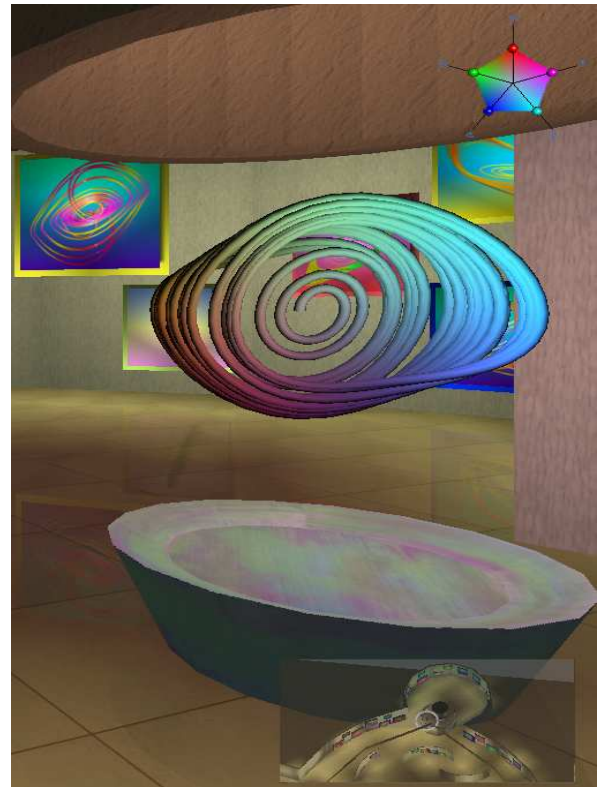


Figure 7. Interaction interface



Figure 8. Multiuser interaction system

The systems allows the registration of the sound tracks produced by the students and of the patterns of the attractors visualized on the screen.

V. CONCLUSION AND FUTURE WORK

In this paper we have presented new applications in the *Virtual Museum of Chua's Attractor*. After experimenting the constructivist approach with different classes of students, from elementary to high school, we decided to implement new applications, transferring physical activities into virtual ones, by using VR technologies and many related software we have developed for the visualization, musification and sonification of Chua's attractors.

The creative artifacts the students have realized such as images, sound and musical compositions, as well as their

emotion during the educational path, allow us to think very positively about this system and its potentials. The environment can be studied on the net and future work foresees a wider experimentation. We would also like investigating the collaborative way of learning in a class.

In the future we will collect feedback from student experiments, giving the evidence that the application and underlying pedagogical and didactical concepts are relevant and attractive.

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