Diving into Infinity: A Motion-Based, Immersive Interface for M.C. Escher’s Works

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Abstract
We describe a Kinect-based interface for navigating M.C. Escher’s works. Our interface is based on the Kuatro, a framework for developing motion-based interactive virtual environments. Kuatro utilizes the Model-View Controller (MVC) architecture and Open Sound Control (OSC) to provide an expandable environment for motion-sensor based installations for composers, artists, and interaction designers. We present a case study based on “Print Gallery”, an intriguing, self-similar work created by M.C. Escher in 1956. Our interaction design involves a Kinect sensor, a video projector, a Kuatro server, and a screen; it allows a user to zoom in and out, as well as rotate the image to reveal its self-similarity, by navigating prerecorded video material. This material is based on previous mathematical analyses of “Print Gallery” to reveal / explain the artist’s depiction of infinity. We discuss adapting this approach to other M.C. Escher works involving infinity.

Keywords
Interactive art, motion-based interaction, M.C. Escher, video animation, Kinect-based interface, art installation, human-computer interaction.

Introduction
We present “Diving into Infinity”, a motion-based, immersive interface for exploring M.C. Escher’s works involving use of infinity and self-similarity (see Figure 1). Our system is built using the Kuatro, a framework for developing motion-based interactive installations for composers, artists, and interaction designers [1].¹

In this paper, we focus on M.C. Escher’s “Print Gallery” (“Prentententoonstelling”), an intriguing lithograph involving infinity through recursion, created by the Dutch artist in 1956 (see Figure 2). While Escher was not a trained mathematician, he had strong mathematical intuitions, which he was able to depict through his artwork.

In Escher’s own words, the depiction of infinity in “Print Gallery” is experienced as follows:

“Through a doorway” (see Figure 2, bottom right), “we enter a picture gallery. … We first meet a visitor with

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his hands on his back and then a young man who is about four times taller. … He looks at the last row of prints hanging on the wall. He sees the ship, the sea, and the houses of a town. … In one of the houses a woman is looking out of an open window. She is also a detail of the print that the young man contemplates, just like the sloping roof below her, under which the gallery is housed.” [2, p. 67]

So, we can enter the print gallery again, through that doorway, … and continue going around, and around the blank center, endlessly, as described by Escher above.

The center in Figure 2 is of particular importance. It is believed that Escher left it blank on purpose. In order for that center to be filled, it would have to contain the complete “Print Gallery” image again and again, in a never-ending inward spiral, getting smaller and smaller towards the infinitesimal.

Escher was quite capable of drawing in extremely small scale, using a magnifying glass. His ability to conceive and draw images with “inward size reduction”, as he called it, can be seen in other works involving the infinite. One example is “Smaller and Smaller (1956). In this image (see Figure 3), in his own words:

“[t]he components continuously halve themselves. In this woodcut I have consistently and almost maniacally continued the reduction down to the limit of practical execution. I was dependent on four factors: the quality of my wood material, the sharpness of my tool, the steadiness of my hand, and especially my keen-sightedness, aided by a twelve-times-enlarging magnifying glass.” [2, p. 41].

In “Print Gallery”, however, Escher chose to draw only one level of the infinite inward reduction. It is clear, he was aware of the blank center’s significance. Perhaps, it is not an accident that he chose to place his signature there.

In our project (see Figure 1), the blank center is filled with visual material generated by Dutch mathematicians Bart de Smit and Hendrik Lenstra [3]. They discovered that, by rotating the image about 157.64 degrees and shrinking it by a factor of about 22.58%, they can automatically generate the inward reduction – and thus fill the blank center infinitely.

Looking through the four images (Figure 1) from our prototype clockwise, the infinite drawing is unfolding in a spiral motion. This creates an effect of immersion into the infinite inward reduction (recursion) of the image, hence the title of our project “Diving into Infinity”. Additional controls allow the user to experience the picture-within-picture (also known as the Droste effect) of the original, unwarped scene. The animations controlled through our interface were produced for the M.C. Escher exhibit “Infinite Universes” [4].

Figure 3. M.C. Escher’s “Smaller and Smaller” (notice the ever-increasing detail in the center).

Our system consists of a Kinect sensor, a video projector, a computer running the Kuatro environment, and a projection screen. The Kinect captures user movement, and passes it to the Kuatro environment. This allows the user to control the rotation and shrinking of the image through movement, enhancing the immersion effect.

To the best of our knowledge, this is the first project to explore motion-based, interactive ways to experience the mathematical beauty of M.C. Escher works.

**Background**

In terms of technology, this project is a continuation of an interactive art exhibit, called Time Jitters. *Time Jitters* is a four-projector interactive installation designed by Los Angeles-based artist Jody Zellen for the Halsey Institute of Contemporary Art in Charleston, SC, USA [1]. The exhibit design includes two walls displaying looping video animation, and two walls with interactive elements. The concept is to create an immersive experience, which confronts participants with a bombardment of visual and sound elements (e.g., see Figure 4 and [http://goo.gl/TIfpPI](http://goo.gl/TIfpPI)).

Time Jitters was instrumental in developing the Kuatro framework used in this project. “Diving into Infinity”, is similar to Time Jitters, as it also provides looping video animation and interactive elements. However, in this project, the two (video animation and interactive elements) have been combined, with the interactive elements controlling the visual unfolding and exploration of different strange loops included in “Print Gallery”. The interaction design is explained more in a later section.
M.C. Escher

Maurits Cornelis (M.C.) Escher (1898–1972) was a Dutch graphic artist who created numerous mathematically inspired works. As mentioned earlier, Escher did not have formal mathematical training, however he was able to intuitively grasp and visually express significant mathematical concepts involving use of polyhedra, recursion, and geometric distortions. His trip to the Alhambra Palace, in Granada, Spain in 1922, was very influential, as it marked a departure from earlier, flatter works towards works using geometric grids, symmetry, and periodicity.

Escher’s newer works are characterized by explorations of infinity through tessellations (special tilings), as well as the use of paradox, illusion, and double meaning [5, 6]. *Tessellation* is the division of a plane using one or more geometric shapes, called tiles. To construct a tessellation, tiles are repeated, and may be warped, rotated, and shrunk, in a periodic way, to fill a plane with no overlaps and no gaps. Escher explored tessellations, graphical metamorphoses, architecture, and infinity – the latter of which intrigued him the most.

Mathematician and Escher scholar, Doris Schattschneider discusses how Escher invokes depictions of infinity to try and answer the “otherwise unanswerable questions” [7]. Infinity “permeates human thought, yet defies human understanding.” Through his works, Escher invites us in a never-ending journey to begin experiencing infinity, and expand our understanding. In Escher’s own words:

“Deep, deep infinity! Rest, dreaming removed from the nervous tensions over a calm sea, on the bow of a ship, toward a horizon that always recedes; staring at waves that go by and listening to their monotonous, soft murmuring; dreaming away toward unconsciousness. …”

[2, p. 124]

Strange Loops

Cognitive scientist, Douglas Hofstadter introduces the concept of Strange Loops to describe works by Escher, Bach, and Gödel [6]. A *Strange Loop* occurs when “by moving upwards (or downwards) through the levels of some hierarchical system, we unexpectedly find ourselves back where we started” (ibid, p. 10). This is related to the notion of self-reference, recursion, and self-similarity found in various natural artifacts and phenomena and explored in the field of Fractal Geometry [8].

Escher produced many works containing Strange Loops, including but not limited to “Hand with Reflecting Globe” (1935), “Drawing Hands” (1948), “Print Gallery” (1956), “Ascending and Descending” (1960), and “Waterfall” (1961). However, according to Hofstadter, “Print Gallery” is the most significant of these works:

“[This is] a picture of a picture which contains self. Or is it a picture of a gallery which contains itself? Or a town which contains itself? Or a young man who contains himself? … Implicit in the concept of a Strange Loop is the concept of infinity, since what else is a loop but a way of representing an endless process in a finite way?” ([6], p. 15)

Interactive Art

In “The Language of New Media” new media theorist, Lev Manovich argues that all art should be considered interactive, as it requires some level of audience participation [9]. For example, visual arts require the user to fill in information of missing details or sculptures may require the user to move around the object to gain a full understanding. Cornock and Edmonds help to clarify forms of interaction by classifying the types of interaction into three categories: static, dynamic-passive, and dynamic-interactive [10].

*Static* art systems are works, such as paintings or sculptures, which do not change, but require the participant to cognitively engage with the art object to gain full understanding.

*Dynamic-passive* art systems are like static works, however some elements of the art object change over time, such as kinetic art.

*Dynamic-interactive* art systems are built upon the other two categories; however, in this case, the art object changes directly through audience participation.

This project, “Diving Into Infinity”, transforms M.C. Escher’s “Print Gallery” from a static piece of art into a dynamic-interactive piece of art. This offers an opportunity for the audience to immerse themselves into the mental/conceptual model of the artist, before it was rendered onto the flat, static 2D drawing. Also, it begs the question of what type of art Escher would have produced, if he had
When Art Meets Human-Computer Interaction

In the context of human-computer interaction, the term interactive art encompasses works that require the interaction of a user, via presence, movement, sound, touch, and more, to create a cohesive artistic experience. Traditionally, artists tend to avoid custom-tailoring their material to please or conform to a wider audience – “selling out” being one term used to characterize this. However, in the context of interactive art, artists need to take into account the end-user in a more formative way, when designing, evaluating, and refining the interaction design. This is not because the audience might use a different context to decode the artist’s work (as explored by reception theory), but mainly because, when interaction is involved, the design needs to connect user tasks and actions, as perceived by the audience, with the artist’s concept and objectives. Otherwise, artists run the risk that their aesthetic concept and objectives may not be understood or experienced by the audience as intended.

In the context of interactive art, audience members become users, and thus may be considered an integral part of the artwork, as they directly control the experience and the articulation / expression / materialization of the artist’s aesthetic statement.

In human-computer interaction it is understood that, in the eyes of the user, the user interface is the system [11]. So, perhaps, in the minds of the audience, the user interface is the artwork. This possibility can be seen in the earlier demo of the Time Jitters exhibit, where members of the audience spend their time exploring the interaction language, as part of their aesthetic experience with the artwork (see http://goo.gl/TIfpPl).

Related Work

This section describes some prior work related to this project. Jacob, et al. present SwarmArt, an environment where user interaction controls the behavior of a swarm-based system [12]. SwarmArt uses a video camera connected to a video-processing server, which determines user movements. The server distributes data via XML providing information about users’ positions. In one exhibit, swarms follow users as they move through the space: they move downward as users get closer, and follow the users’ left-to-right movement.

Rui Nóbrega, et al. present a framework within which a project such as a ours may exist, namely public space interaction for digital buildings and cities [13]. They discuss environments where people interact through public displays, location-based applications via smartphone sensors, and augmented reality systems. The prototype presented herein could easily become a component in a digital building (as interactive wall art), or in a citywide environment.

Kortbek and Grønbæk present four interaction design principles for designing interactive systems to communicate art in museums. These four design principles are:

1. gentle audio augmentation of art works,
2. conceptual affinity of art works and interactive installations,
3. using the body as an interaction device, and
4. consistent audio-visual cues for interaction opportunities.

These proposed interaction design principles are meant to minimize the disruption that may be caused by introducing new technologies into a museum atmosphere. Using these principles, a number of interactive experiences have been designed, as part of a Mariko Mori Exhibition at the ARoS Aarhus Kunstmuseum art museum in Denmark.

Three of these installations, namely “Esoteric Cosmos”, “UFO”, and “Oneness”, were “contemplation installations” – they were used to augment the original artworks with information about the artists’ inspiration and sources. These installations make use of audience movement / positions in the installation space (as per design principle 3) to present and update the augmenting information [14].

The Kuatro Framework

The Kuatro framework is a development environment for building dynamic-interactive music and art installations using motion sensors such as the Kinect, Asus Xtion Pro and Leap Motion.

Edmonds et al. suggest building environments that help artists access lower levels of the computer, i.e., “environments for building environments” [15]. The Kuatro has been designed accordingly to facilitate interaction design, thus allowing artists / designers to focus on their aesthetic objectives. The Kuatro does this by providing a simple framework for building motion-based installation spaces,
while abstracting technological components and hiding complex implementation details of the underlying sensors.

The Kuatro employs a Model-View-Controller (MVC) architecture, combined with Open Sound Control (OSC) for communication between components. The MVC architecture helps hide complex implementation details within the Model and the Controller.

The Kinect sensor data is processed by a Kuatro Client application running on a workstation (the controller component of the MVC architecture). The client sends sensor data to the Kuatro Server (which maintains the model component of the MVC architecture – an XY virtual world representation of the installation space). The server broadcasts the user’s virtual world location to one or more Kuatro View applications (the view component of the system). The views are specific to a given installation and support the various user tasks and actions. The view for this project is discussed in the next section.

Through this architecture, artists / designers only have to learn the OSC messages sent to View modules, as described in [1]. By using OSC to communicate user movement data, a view can be implemented in any language or environment that an artist / designer is familiar with, as long as it supports receiving OSC messages. Such environments include, but are not limited to Processing, Max/MSP, Iannix, and Abeton Live.

Kuatro has been developed in JythonMusic, a development environment for computing in the arts applications based on Python syntax [16]. JythonMusic includes Music and GUI libraries, among other functionality, providing artists an easy to learn API and language to create View modules.

For the more technically advanced artists or designers, the Kuatro framework allows users to create their own controllers by using the OSC protocol for Controller-to-Model communication, as described in [1]. For instance, early prototypes for this installation explored using a mouse controller and a smartphone gyro (pitch/yaw/roll) sensor.

The following section describes the interaction language for a Kinect-only interface. This interface was selected due to its simpler setup (i.e., less technology to configure) and naturalness of user actions (i.e., exploring involves only walking around and stepping onto a virtual button on the floor). Earlier prototypes were more cumbersome (harder to discover / learn) in terms of user actions, as they involved various combinations of walking and navigating through wrist movements or finger gestures, while holding a smartphone, and/or using a graphical user interface on a smartphone or tablet.

**Interaction Design**

The “Diving to Infinity” installation requires a Kinect, a projector, and a computer connecting the two. The Kinect and the projector are both placed behind the user (see Figure 5). In terms of dimensions, the environment consists of a 20’ x 14’ (6.1m x 4.3m) space approximately, with one projector displaying content on a wall / projection screen on the other side of the space. The projector and the Kinect are co-located, possibly on the same stand, which is tall enough to avoid shadow obstruction by the user interacting with the space.

The interaction design supports the following user tasks:

- **Task 0**: Begin interaction.
- **Task 1**: Explore original “Print Gallery” (magnify it for more detail, or see it from afar).
- **Task 2**: Unfold the “mysterious” warping of Escher’s original to produce a flat drawing (see Figure 6).
- **Task 3**: Explore the picture-within-a-picture effect in the flat drawing (see Figure 7).
- **Task 4**: Re-warp the flat drawing to generate Escher’s original.
- **Task 5**: Explore the picture-within-a-picture effect in Escher’s original (see Figure 1).
- **Task 6**: End interaction.

The following section describes how these user tasks are mapped to low-level user actions (involving body movement).

**Mapping User Tasks to Actions**

This section describes the interaction language used to map the above user tasks to low-level user actions. These actions involve walking around the installation space, and stepping onto the virtual button.

As mentioned earlier, the user’s location is tracked using one Kinect. The Kinect’s triangular sensing area is mapped to an XY plane overlapping the overhead view of the installation space (see Figure 5). The Kinect sensor data is processed and sent to a view application, which implements the interaction language described herein. This interaction language consists of the following user interface states and corresponding state transitions.

**State Transition Diagram**

The “Diving into Infinity” user interface (UI) supports the following states, and transitions between states (also, see Figure 8):

- **State 0**: When there is no user inside the installation space, the system is in State 0. In this state, the UI displays a small, original “Print Gallery” (shown in Figure 2). This indicates the system is ready to start. As soon as the user enters the space (see Task 0), the system switches to State 1. The system always returns to State 0, when the user exits the installation space, from any other state (see Task 6).
- **State 1**: When the user enters the space, the system switches to this state. In this state, the UI allows the
user to explore the original “Print Gallery” (see Task 1). This is accomplished by mapping user movement along the X-axis to image position on the screen (i.e., the image becomes “sticky” – it follows the user’s lateral movement). Also, the UI maps user movement along the Y-axis to image size (i.e., the closer the user to the projection screen, the larger the image).

- **State 2**: This state is entered when the user steps on the floor button (see Figure 5). Standing in this specially designated area, for a preset number of seconds, activates the button. In this state, the system unwraps the original “Print Gallery” to the “natural”, flat version of the image (see Task 2). Also during this time the button becomes inactive, in effect, making the unwarping an atomic (undivided, modal) user action (i.e., it cannot be disturbed once started).

- **State 3**: This state is entered automatically when the unwarping from state 2 is finished. In this state, the UI displays the “natural” (unwarped) version of the video (see Figure 7), which continuously zooms into the unwarped image, revealing the infinite regression (picture-within-a-picture effect) hidden in it (see Task 3). Similarly to state 1, the UI maps user movement along the X-axis to video position on the screen (i.e., the video animation follows the user’s lateral movement). Also, the UI maps user movement along the Y-axis to video size (i.e., the closer the user to the projection screen, the larger the video animation).

- **State 4**: Similarly to state 2, this state is entered when the user steps on the floor button. In this state, the system re-warps the “natural”, flat version of the image back to the original “Print Gallery” (see Task 4). This action is also atomic (undivided, modal), i.e., it cannot be disturbed once started.

- **State 5**: This state is entered automatically when the unwarping from state 4 is finished. In this state, the UI displays the original version of the video (see Figure 1), which continuously zooms (swirls) into itself, revealing the infinite regression (the picture-within-a-picture effect) hidden in it (see Task 5). Similarly to state 1, the UI maps user movement along the X-axis to video position, and user movement along the Y-axis to video size.

Any time the user decides to exit the space, the system (upon sensing the user is gone) returns to state 0.

This interaction design has evolved through several prototypes and usability tests with different users. We feel that this is still a work-in-progress, as there are many different ways to connect user actions to experiencing and navigating the infinity in “Print Gallery” (and related Escher works). A demo of the system is available here: http://goo.gl/FZnrbN.

As mentioned earlier, our system reuses video material produced for the M.C. Escher “Infinite Universes” exhibit at the Parque de las Ciencias (Science Park) at the Alhambra, in Granada, Spain [4].
Conclusion

“Diving into Infinity” is a project for developing interactive experiences of M.C. Escher’s depiction of infinity in his works. The prototype described focuses on the artist’s 1956 work “Print Gallery.”

Our system provides one way to navigate Escher’s depictions of infinity, by utilizing the Kinect sensor, a video projector, a computer running the Kuatro environment, and a projection screen. The Kinect sensor captures user movement, passes it to the Kuatro environment. This allows the user to control various aspects of the inward size reduction and rotation characterizing “Print Gallery”. This control through movement enhances the immersion effect, and introduces a new way to experience Escher’s works – a way that was not possible with the technology available to the artist.

Our interaction framework can be adapted to develop interfaces for other M.C. Escher works that use a similar construction approach, such as “Smaller and Smaller” (see Figure 3) and “Fishes and Scales” (1959), among others. We intend to develop interaction designs for other Escher images as future work.

To the best of our knowledge, this is the first project that explores motion-based, interactive ways to experience the mathematical beauty and depiction of infinity in M.C. Escher works. In the artist’s own words:

“When one dives into endlessness, in both time and space, farther and farther without stopping, one needs fixed points or milestones past which one speeds. Without these one’s movement does not differ from standing still. There must be stars along which one shoots, beacons from which one can measure the road covered.” [2, p. 124]

We hope that our work provides a new way to experience this “diving into endlessness”, which is possibly consistent with what the artist himself would have designed had he had access to our technology.

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Figure 8. State transition diagram for the UI of “Diving into Infinity”.

References


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Bill Manaris is a computer science researcher, educator, and musician. He is Professor of Computer Science, and Director of the Computing in the Arts program, at the College of Charleston, USA. His interests include computer music, human-computer interaction and artificial intelligence. He explores interaction design and modeling of aesthetics and creativity using statistical, connectionist, and evolutionary techniques. He designs systems for computer-aided analysis, composition, and performance in music and art. He studied computer science and music at the University of New Orleans, and holds an M.S. and Ph.D. degrees in Computer Science from the Center for Advanced Computer Studies, University of Louisiana. Manaris is Associate Editor of the International Journal on Artificial Intelligence Tools, and has recently published a textbook in Computer Music and Creative Computing.

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