Shedding Light On Shadow: Real-time interactive artworks based on cast shadows or silhouettes

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ABSTRACT

Digital shadowing is a source of interest in immersive and interactive artworks because it enhances the feeling of presence, and because it is a very intuitive and engaging interaction "device". After a presentation of some major pieces in shadow-based artwork along two categories (silhouette-based digital shadows and cast shadow-based digital shadows), we propose a real-time software platform that can produce these two types of shadows from video capture and image processing. The processing is divided into image analysis for shadow extraction, calibration, and special effects. It is made highly flexible and parameterized, so that it can fit various configurations. Two specific configurations are illustrated because of their genericity: one for infrared light silhouette-based shadow and live performance, and one for both digital shadowing categories and interactive art installations with visible light. We then present some of the applications of such a platform through vari ous live performances made by two theater companies involved in a collaborative project with scientists. The examples confirm the wide variety of scenographic setups in which shadow can be involved as a key component.

Categories and Subject Descriptors

H.5.1 [**Information Systems**]: Information Interfaces and Presentation—*Multimedia Information Systems; Artificial, Augmented, and Virtual Realities*; J.5 [**Arts and Humanities**]: Performing Arts (e.g. dance, music)

General Terms

Algorithms, Design, Experimentation, Human Factors

Keywords

Augmented Reality, Real-time Image Processing, Digital Art, Digital Shadow, Video-scenography, Interactive art

1. INTRODUCTION

Shadow is a recurring theme in arts, literature, and philosophy since the Antiquity and Plato's *Cave* where cast shadows symbolize the limited perception of the world by its prisoners. Shadows in the visual arts have mainly appeared since the Renaissance through early perspective artworks. They were used to enhance the 3D perception of the scenes, and made light sources explicit. For this reason, perspective and shadows can be considered as early attempts to render artworks immersive by giving the user a feeling of "being there". In addition to immersion and perspective perception, shadows were also used to give a sense of volume through shading. When combined with the real world, as in the case of Masaccio's fresco *Tribute Money* in Santa Maria del Carmine (Florence), the light source of the artwork could be purposely chosen to coincide with a physical light source in the church, thus making this type of artwork an example of early Augmented Reality. Last, shadows have also be used for their symbolic meaning, representing evilness and hidden dark sides of humanity.

For similar purposes of immersion and augmentation of the real world, shadows can also be found in contemporary visual artworks, and we are mostly interested in interactive digital arts in which video-projection reveals and highlights shadows through *digital shadows*. Since this domain is made up of a wide variety of works, and since the technological setups are quite diverse and rarely documented, our purpose in this article is to offer a synthetic and cohesive artistic analysis of recent digital works that refer to shadows, together with an accurate description of our technological platform for developing shadow-based artworks. To our knowledge, this is the first attempt to unify a body of works that have played a significant role in the recent developments of digital arts. This article intends to cover both the descriptive and analytical artistic sides, and to address both the technological and scientific issues raised by that type of work.

In Section 2, we present interactive digital works that use virtual shadow as a major component of the installation. These works are subdivided into two categories depending on the input used to produce the virtual shadow, whether cast shadow or silhouette. Section 3 describes two combinations for the relative positioning of a video-projector, a camera, and a light source together with a platform developed for the implementation of virtual shadow-based real-time interactive artworks. Last, in Section 4, several virtual shadowing installations and performances based on the platform are described and analyzed together with their applications in social and educative activities.

2. DIGITAL SHADOW ARTWORKS

Interactive artworks based on shadow offer an augmented visualization of the physical world through the addition of a digital shadow. Because of this configuration, all these works can be classified as Augmented Reality installations in which the physical world is overlaid with digital information, here the video-projected augmented shadow. We define two categories of shadow-based artworks depending on the source of the digital shadow: Cast Shadow-Based Shadow (CSBS) artworks for a physical shadow generally combined with video-projection, or Silhouette-Based Shadow (SBS) artworks for digital shadow built from a silhouette capture (see Figure 1).

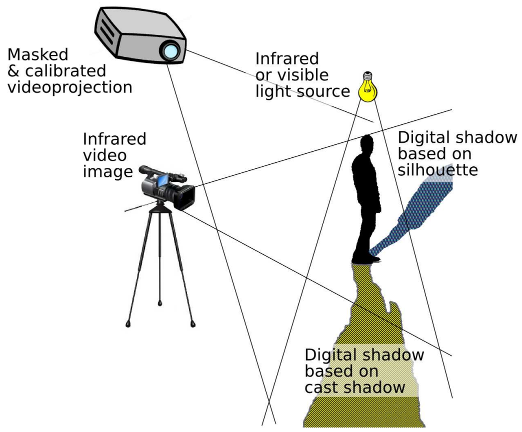

Figure 1: Cast Shadow-Based Shadow (CSBS) through physical light occlusion, and Silhouette-Based Shadow (SBS) through silhouette projection.

The first category, CSBS artworks use a physical light shadow as a basis of the visualization, and therefore rely on the extraction of the visible or non-visible shadow cast by an occluder (the onlooker) with respect to a visible or an infrared (IR) light source. In these works the digital shadow is produced from the capture of a cast shadow, and the digital shadow must be accurately registered with the cast shadow it originates from. If the light source is in the visible range, the overlaid digital shadow must fill accurately the dark area of the cast shadow with video-projected light. In the case of IR lighting, the digital shadow reveals the invisible shadow through video-projection.

The second category, SBS artworks, is based on the extraction of the onlookers' silhouette and its digital conversion into a virtual cast shadow with no corresponding physical light source. Since the virtual shadow is video-projected, it is generally brighter than the background contrary to a digital shadow based on cast shadow that is projected into a dark area. For SBS artworks, registration is less critical than for CSBS works since there is no physical shadow it has to be aligned with. The criteria for alignment in SBS are mainly perceptual: the onlooker has to be convinced that the shadow is really hers. The belief in the virtual shadow by actors does not depend solely on visual clues, but mainly results from the correspondence between their own movements and the perceived shadow motions. At the visual level, two main constraints exist however: the feet of the shadow should be located at the user's feet, and the orientation of the shadow should correspond to the shadow t hat would be cast if the camera was replaced by a light source. At the behavior level, the time delay between the shadow capture and the virtual shadow display should be short enough to make the actor perceive that her own gestures are synchronized with the shadow movements. We will return to these issues in Section 4 when examining digital shadow-based artworks. SBS and IR lit CSBS artworks can be confused because of the invisibility of the physical IR-light cast shadow in CSBS.

2.1 Cast Shadow-Based Shadow (CSBS) Artworks

Our interest in shadow-based artwork started when working on video-scenography rehearsals for a theater play in which one of the spotlights was partially masked by a grid-shaped gobo[1]. Instead of considering video-projection and spot-lighting as two conflicting entities, we were exploring various mixes of these two types of light such as blending the video-projection with a dimmed colored spotlight. When using the gobo, we came to the idea of video-projecting inside the shadows of the gobo. For this purpose, we took a picture of the partially shadowed stage from the video-projector location. Through a quick thresholding and calibration procedure, this picture was then converted into a black and white bitmap and used to mask the video-projection in the lit parts of the stage so that it would only be visible in the shadows of the gobo. Maskin g and calibration were approximate, but the inaccuracies of these processes instead of harming the visual rendering, provided the spectators with a nice feeling of depth and volume. Later we decided to rework this setup in an interactive manner by analyzing a live video image, extracting automatically the dark zones, and using them as masks for the video-projection. This is one of the purposes of the platform presented in Section 3.

Cast shadow has been used in several artworks to reveal a "hidden" image that can only be perceived under specific conditions of lighting (a unique and accurately located point source) and shadowing (on a plane projection surface). For example, Tim Noble and Sue Webster[2] build sculptures out of garbage or familiar objects to reveal images that transcend the reality of these objects by showing unexpected shadow shapes such as a portrait or a sitting couple. These works reverse the traditional meaning of shadow that represents dark impulses or irrationality.

CSBS works draw their effects from the additive properties of emitted light. In the case of a single light source, the light intensity in a shadowed zone is weaker than in the neighboring lit zone. For very powerful light sources, the darkness of shadowed zones can be used to reveal video-projection that is too dimmed to be perceived in the lit zone (e.g. *Body movies* by Lozano-Hemmer mentioned below). For the case of two or more light sources, CSBS works can reveal video-images that are only visible if only one of the light sources is received. In *Movie-in-Shadow* [9], two video-projected images with complementary colors are accurately superimposed so that the resulting image is a uniform white color. By occluding one of the two light sources, the passers-by reveal the complementary image inside their cast shadows. A similar revelation process is offered by Rafael

[1] A *gobo* is a piece of metal with shaped holes that is placed in front of the spotlight and produces a pattern of light.

[2] http://wikipedia.org/wiki/Tim_Noble_and_Sue_Webster

Lozano-Hemmer in *Body Movies*[3] by showing video images inside the cast shadows of the passers-by. These shadows are projected at various scales depending on the distance of the onlookers that are blocking the light of the spotlights. The variety in shape and scale of the silhouettes is combined with the video stream into a single fantastic scene.

Cast shadows can also be used in a playful way as a complementary graphical element to sculpture, whether static or in motion. Kumiya Mashita[4] and Fred Eerdekens[5] both use a light spot that projects a single and clear cast shadow of a sculpture on a wall. The shadow reveals shapes of the sculpture that cannot be seen from the normal onlookers position, and combines them with the visible shapes of the sculpture into a coherent and puzzling artwork. Closer to the topic of our research, even though it has no digital process, the *Night Shadow Project* by Michael Neff[6] consists in outlining the shadows cast by public lighting at night. It has in common with our work to augment the cast shadow (graphically in his work and digitally in our approach), and to leave a trace of a light effect even when the conditions have changed (through painting in his work, and through gr aphical feedback in ours).

All the CSBS artworks we have presented so far do not make use of digital shadowing techniques, but rely instead on a visible light shadow. On the contrary, the artworks presented in the next sub-section (2.2) are based on digital shadows obtained through the video capture and extraction of the silhouette. To our knowledge, these works represent the mainstream approach to digital shadowing even though it can also be based on cast shadow capture. The interesting feature of CSBS artworks is that they can result in the complementary association of video-projection light with spotlights or natural lights. Our hybrid platform described in Section 3 can process both CSBS and SBS setups.

2.2 Silhouette-Based Shadow (SBS) Artworks

Shadow Play is an Asian traditional form of theater that spread through Europe at the 18th Century and known in France as *Ombres Chinoises* (Chinese Shadows). Whereas originally designed for articulated flat puppets, Shadow Play has since been extended to whole or partial human body animations. The basic setup consists in using a strong and horizontal light beam to project the silhouette of the puppets or performers on a semi-opaque surface. This traditional form of theater has been retargeted to digital art by capturing the video image of a silhouette and using it as a mask for synthesizing a virtual shadow through video-projection.

The SBS digital artworks can be roughly divided into two categories depending on whether the virtual shadow is used as an interactor or as a visual and aesthetic component in the installation. The reason for using a silhouette-based shadow as an interactor, is to "simplify" the onlooker's presence in the installation by turning her into a legible and simple black shape. The silhouette keeps enough similarity with the body to make interaction transparent and intuitive, while it avoids clutterring up the visual rendering of the work with a realistic view of the user. In such installations, it is generally the border of the silhouette that serves as an interactor.

A pioneering use of the SBS setup is the *Videoplace* environment created by Myron Krueger in 1977. Originally designed as a responsive environment, this artwork developed "the basis for a new aesthetic medium based on realtime interaction between men and machines" [6]. The performer invited to play in *Videoplace* was interacting with the computer-generated images through her SBS shadow. The innovation in *Videoplace* was to consider interacting through the user's shadow as the main artistic issue in this environment, upstaging the visual rendering accordingly. Despite such early shadow-based approaches to interaction, there remains numerous possibilities and future exciting artworks that can certainly further this line of artistic research, such as David Rokeby's *Silicon Remembers Carbon*[7].

Some of the most representative examples of SBS installations are Zachary Booth Simpson's *Mine-Control*[8] works. In his works, the silhouette contour is used as an obstacle to control a flow, the bouncing of a ball, the motion of an animal and the waves on a surface. In his article [8], Golan Levin quotes several digital artworks controlled by hand and arm shadows, including his own work *Messa di Vocce*[9] (in collaboration with Zach Lieberman, Jaap Blonk, and Joan La Barbara), in which silhouette is used to generate visual elements combined with voice analysis.

The SBS artworks that exploit shadow as an aesthetic component generally do not assign a specific interactive function to the user's shadow projection. The shadow can be taken as it is, as a schematic and yet recognizable trace of a presence. Such SBS digital artworks are the ones closest to the ancestral form of shadow play. Scott Snibbe's *Outward Mosaic*[10] collects onlookers' animated shadows into a live and refined gallery of multi-scale loop videos of shadows. The control relationship between the user and her shadow is reversed when the shadow appearance is modified by the user's behavior. In Philip Worthington's *Shadow Monsters*[11] hand shadows are turned into monster's head profiles through the addition of frightening graphical elements.

Live performance has also a strong interest in introducing shadows on stage for various scenographic purposes. For example in Philippe Decouflé's *Sombrero*[12] ballet, shadow is used for scale effects or mirror behaviors. A wide range of shadow-based scenery effects are also presented in Chunky Move's *Mortal Engine* dance performance. These effects combine music- and gesture-controlled generative graphics with silhouette capture to immerse the dancer's shadow into a flow of hypnotic visual effects.

By altering the behavior of the shadow and introducing discrepancies between the shadow appearance and the human body that produces it, the pseudo-shadow is likely to question our presence to the world. Zachary Booth Simpson's *Shadow*[13] with Adam Frank presents a virtual shadow that has no physical cause, and that reacts to and combines with the onlooker's own cast shadows. Similarly, *Digital*

[3] http://www.lozano-hemmer.com/body_movies.php
[4] http://kumiyamashita.com
[5] http://www.fred-eerdekens.be/
[6] http://michaelneff.com/

[7] http://homepage.mac.com/davidrokeby/src.html
[8] http://www.mine-control.com/
[9] http://www.flong.com/projects/messa/
[10] http://www.snibbe.com/projects/interactive/
[11] http://www.worthersoriginal.com/viki/
[12] http://www.culturekiosque.com/dance/-reviews/decoufle_sombrero.html
[13] http://www.mine-control.com/shadow.html

Shadow[14] by Alessandro Corsini and colleagues introduces so-called rebellious shadows that quit their mirror behavior to switch to unexpected motions corresponding to previous recordings of the same silhouette. We will present similar investigations in Section 4 for live performance with children, teen-agers, and young disabled adults.

Last, shadow can also be used in artworks as a medium between the real world and a virtual one. In the *Abstract*[15] installation by Joëlle Bitton, visitors are invited to a meditation Japanese garden world by discovering it through their transparent shadows. In the Augmented Virtuality installation *Gate 3.5*[16] by Bertrand Planes, the onlookers have their shadow projected inside a 3D virtual world. In addition to enhancing their feeling of presence in the virtual world, the shadow also serves the purpose of a kind of "non-tactile" contact with the virtual world, and a discovery of its geometry through virtual shadow-based exploration.

3. A PLATFORM FOR SHADOW-BASED INSTALLATIONS

This section describes a generic platform for shadow and/or silhouette extraction, and its use for various output effects through image synthesis. The input to this software is an IR monochromatic image that possibly contains both a silhouette and its cast shadow. The output is one or two virtual shadows rendered from one or both of them.

The setup for experimenting with shadows is presented in Figure 2. It shows the most complex case with two types of cast shadows: the blocking of the video-projector light and the blocking of the spotlight (visible or IR light). The video-projector light shadowing is considered as an uninteresting parasite shadow. We therefore focus only on the cast shadow that results from blocking the light emitted by the light-spot. In the case of visible light, the digital shadow must be calibrated to the physical shadow. The setup for digital shadowing offers a wide variety of combinations that have been studied exhaustively by Chan and Gagneré [4]. They mostly depend on the relative positions of the user, the camera, the video-projector, the spotlight, and the "screen". We only focus on two emblematic and illustrative ones; they are illustrated by Figures 3 and 4.

First, Figure 3 shows a top view of a configuration dedicated to SBS that has been investigated by the theater companies involved in the project and in this article. In this configuration, a translucent screen is located behind the performer and receives both the video-projection and a powerful IR light so that the performer's silhouette can be easily extracted from the lit background. Rear video-projection avoids the performer's occlusion of the video-projector light that otherwise can occur in front projection. This configuration is well-suited for live performance because the shadow is clearly visible for the audience, and does not require complex calibration procedures. It has been used in several performances and educational activities with children by the theater companies. They are presented in Section 4.

Second, the configuration shown in Figure 4 has only been exploited in the laboratory work for tuning up the platform. This second configuration relies on image analysis for the extraction of physical cast shadow.

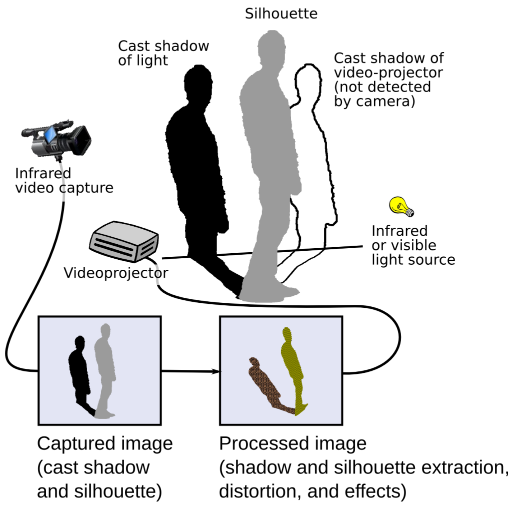

Figure 2: Image input/output in the platform for shadow-based works.

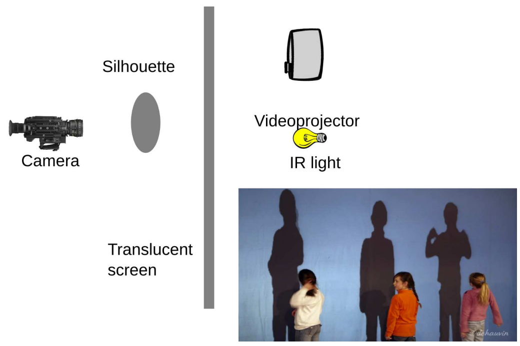

Figure 3: Top view of SBS IR light configuration, and sample performance.

The two main steps in computational processing for digital shadow-based installations are *image analysis* for real-time shadow or silhouette detection, and visual effects through *image synthesis* (see Figure 5). Both are implemented with GPU-programming (shaders) for optimization and portability purposes.

The image analysis modules extract two masks from an input B&W video image, corresponding respectively to cast shadow and silhouette by distinguishing the pixels according to their homogeneity: shadows tend to be more homogeneous than silhouettes. The image analysis modules are followed by an image synthesis component that uses the shadow and silhouette masks to render a virtual shadow from one of these elements or both, and adds optional artistic effects such as fire, water, particles, virtual 3D components, etc. In the case of cast shadow input (CSBS works), the output shadow is calibrated so as to be embedded into the cast shadow. In the case of silhouette input (SBS works), the virtual shadow is generally displayed as a fake cast shadow, anchored at the feet of the onlooker, and projected opposite to the camera considered as a virtual light source. We examine these two components (image analysis and image synthesis) in turn.

[14]http://www.digitale-medien-bremen.de/
[15]http://www.superficiel.org/joelle/art/pages/abstract.htm
[16]http://www.bertrandplanes.com/-pages/Gate35%20Panorama.php

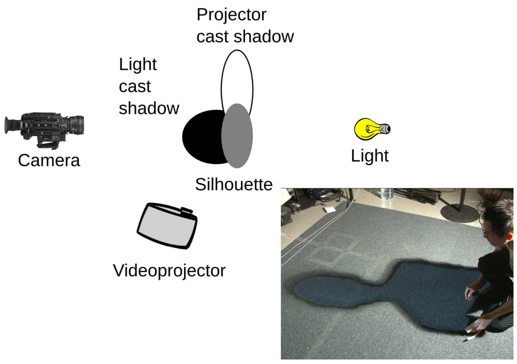

Figure 4: Top view of IR or visible light CSBS and SBS, and sample laboratory capture.

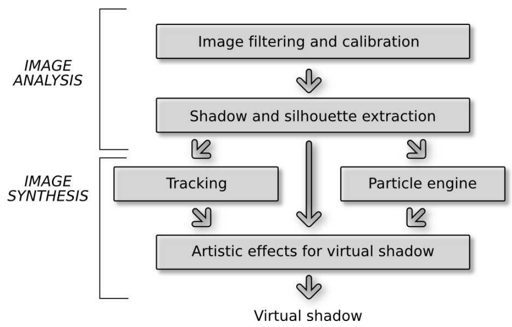

Figure 5: Full pipe-line.

3.1 Real-time Image Analysis

Computer Vision plays a central role in Augmented Reality applications because it is used for registering the virtual elements with the physical world through 3D reconstruction and calibration procedures. Since the augmentation of shadow in CSBS and SBS artworks is based on the video-projection of a digital shadow, these works belong to Spatial Augmented Reality (SAR) described by Bimber et al. [2]. In SAR, video-projection is used to overlay digital information on the physical world by carefully registering the digital information with its corresponding location inside the physical world.

In CSBS works, the cast shadow of the user blocking a light beam (whether visible or IR) must be extracted. In SBS works, the user's silhouette has to be obtained and projected from a virtual point light into the digital scene. In both cases, cast shadow and silhouette detection are made in the IR spectrum to avoid visual feedback by capturing the video-projected image by the video camera (video-projector light contains very little IR and is almost invisible to an IR video capture). The IR lighting is obtained either by using an IR spotlight if the installation is in the dark, or by using a visible light spotlight that contains IR in the case of CSBS works. In both cases, video capture for image processing is made solely in the monochromatic IR spectrum.

Whereas IR image analysis has been extensively studied to track objects that emit IR light, the issue in our work is to track parts of the image that do not receive IR light: either cast shadows due to the user's occlusion (Figure 4), or silhouette of the user(s) standing in front of a bright surface or a translucent surface on which IR light is projected (Figure 3). The image processing part of SBS works is a simplified form of chroma keying in which a silhouette is separated from its background. Instead of color separation, silhouette extraction relies here on light intensity separation and background subtraction because it is made on a monochromatic IR image. Similarly, cast shadow extraction is also based on the detection of darker areas in the image. The modules for image processing are given in Figure 6.

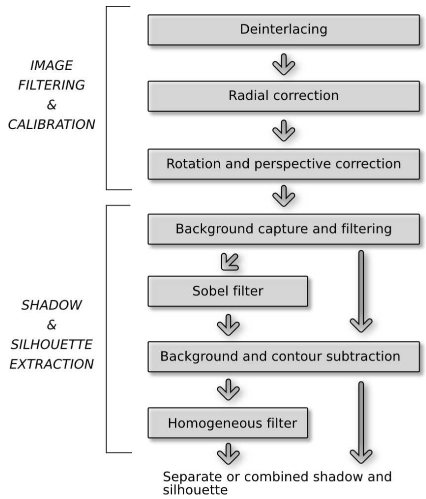

Figure 6: Image analysis pipe-line.

After video deinterlacing, the first part of image processing concerns image calibration. First, the deinterlaced IR image is transformed into a plane image through lens radial correction. Then two transformations are applied (rotation and perspective) in order to register the image to the user's position in the scene. After calibration the video-projection of the cast shadow matches the physical cast shadow in case of a CSBS installation.

The second step in image processing consists in cast shadow and silhouette extraction. First a background image is computed through a median and Gaussian filter on 5 images captured over 70 frames [7]. The background contours are filtered and combined with the background image for shadow and silhouette extraction through background subtraction. Contours are highlighted in the extraction process because some of the renderings use them either for aesthetic purposes (outlining the shadow edge) or for functional purposes (using the contour of the shadow for interaction). Background subtraction is based on logarithmic intensities because it results in better quality, and is less sensitive to threshold selection [11]. A final filter separates the cast shadow from the silhouette by using the property of background subtraction resulting in more homogeneous regions in the shadowed part of the scene than in its mobile parts [7].

3.2 Real-time Image Synthesis

The masks associated with shadow and silhouette are used by the image synthesis modules to generate virtual shadows. Three main components build up the image synthesis part of the platform: a module for computing and highlighting the bounding boxes around the two masks, a particle engine, and the rendering modules for visual effects.

The **tracking module** relies mainly on a geometry shader that computes the minimal and maximal coordinates of the shadow and silhouette areas to obtain and display their bounding boxes. These data can be used, for example, by the particle engine to attract particles towards the center of the bounding boxes, and make them converge towards the shadow or the silhouette whatever their positions in the field of view of the camera. The bounding box is calculated on a sub-sampled image to reduce the computational cost.

The **particle engine** belongs to the category of physics engines. They are very popular in the game and digital art communities where they are used to add realism to animation. Particles are point masses that are controlled by a force and interactions with other particles or with obstacles. We have developed an open GPU framework for animating and rendering particles. Fragment shaders compute the particle dynamics and vertex shaders update the positions through vertex texture fetch. The engine allows for the computation of particles bouncing on the contour of an object (here the shadow or the silhouette) according to the surface norm.

Two artistic particle renderings have been studied. First, an ambient visual display shows falling particles as white drops, and lets them bounce on the surface of the shadows. Second an interactive rendering shows particles as words that are attracted by the center of the shadow, and bounce on its surface. If the shadow remains still for a while, the words will eventually stabilize on its surface.

The last processing pass of virtual shadow rendering consists of a wide variety of fragment shaders that take as input the calibrated and distinguished areas of shadow and silhouette, and use them to generate various visual renderings of a digital shadow that are projected in the physical shadow in the case of CSBS artworks, or anchored to the user's feet and projected on a plane surface (wall, vertical screen, or floor) for SBS works. We only focus on a few rendering modules that were of particular interest for the technical development of artistic installations.

The purpose of the **colorimetric compensation** [1] module is to "erase" the shadow by video-projecting a bright virtual shadow that compensates the decrease of illumination due to cast shadow. This module is targeted for CSBS installations with a visible light. Since no full visible light range video capture is available in our setup, the compensation cannot rely on a captured image and on the comparison of the lit and non-lit areas. It is based on the manual tuning of a uniform lighting of the floor surface. Better results could be obtained through live color video capture.

The **feedback module** is mainly intended for installations with non-visible light. Its purpose is to reveal a shadow (whether CSBS or SBS) and to display it with a feedback rendering loop in order make the trace of the user's motion explicit. This module can be applied to various video fillings of the digital shadow: uniform color, texture, or video. This effect also gives the onlookers a clue to the user's motion speed according to the length of the shadow feedback trail.

In the same vein as the particle engine, two modules for **fire and a water effects** modify the shadow masks at the pixel level, based on a simple physics of fire or water, and a noise texture to add randomness to the motion and the coloring. In the fire module, the shadow is colored with a moving and distorted fire texture, and the border pixels are displaced towards the top of the image in combination with the noise texture. The geometric distortion and color changes of the water effects are controlled by particle displacements generated by the particle module described above.

Last an **Augmented Reality** module is the combination of a texture or a fixed video and a mask that highlights a foreground element of the image on which the shadow can be cast. This kind of simple augmentation can only work for an image of a plane shadowed surface such as a fence or a wall. For more complex geometrical scenes, it is necessary to reconstruct the geometry of the photo or video as described by Jacquemin, et al. [5]. Another solution is to use the shadow for Augmented Virtuality by projecting the flat shadow inside a 3D virtual scene, in which the geometry can be used to compute the shadowed areas.

4. SAMPLE SHADOW ARTWORKS

As an application of the platform described in the preceding section, this section focuses on examples of SBS artworks, and offers new insights to digital shadowing. There are natural motivations for using SBS in the performing arts: The tradition of Shadow Play makes the audience conventionally understand the SBS as a shadow projection of the actor and dancer due to a virtual horizontal light placed in the audience. The lack of continuity between the performer and her shadow does not break this rule. On the contrary, it reinforces the magical effect of projection that can be found in many traditional narratives such as Plato's *Cave* or Pliny's *Clay modeler Butades*. Last, using a shadow cast on a floor is not easily perceived by an audience because the perspective dramatically diminishes the visual effect of horizontal images, and because a single spotlight makes it difficult to light up the whole stage.

4.1 Sample SBS Dance Scenography

SBS has played a major role in the theater play *Les Révélations d'une ombre*[17] by co-author *Georges Gagneré* in which the seemingly autonomous shadow of a dancer played in time and space with the performer. Four real-time effects were used

- In Figure 7.a, the SBS setup allows us to produce in real-time chronophotographic views of the dancer's movements, inspired by the famous 19th century Muybridge's studies on human locomotion. The various shadows are triggered by notes of music played on stage by a saxophonist.
- Again through the SBS setup, the live shadow of the dancer is shrunk and put in a virtual maze as if she were located inside a video-game (see Figure 7.b). The dancer moves her body and finds the appropriate interactions that will make her progress.
- Figure 7.c shows the cast shadow of the dancer in the white video-projected light behind a screen. The silhouette is shot by a camera in front of the stage and is symmetrically projected as a digital shadow on the second half of the screen. This setup allows us to create several doubles with delays and buffered images that multiply the possibilities of additional characters.
- Last, with the SBS setup and a symmetry of the projection, the dancer plays with her shadow to discover strange topologies musically created in real-time by a saxophonist (see Figure 7.d).

[17] http://www.didascalie.net/lrdo

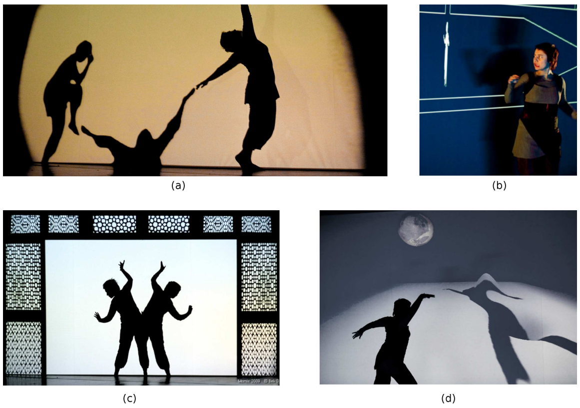

Figure 7: *Les Révélations d'une ombre*, 2009.

The use of the setup presented in Figure 3 offers appropriate conditions to allow the SBS be out of the performer's control. It opens the possibilities to experiment a dialogue in real-time with the living shadow projection of the dancer (among others, inspiring autonomous shadow examples are the *Peter Schlemihl's Remarkable Story* by Adelbert von Chamisso, or *The Shadow* by Hans Christian Andersen). The theme of the monstrous metamorphosis was developed for expressing the secrete ambitions of control from the musician character towards his dancing creature. The setup offered possibilities to develop an initiatic quest by having the shadow counterpart making an extraordinary journey to free the obsessed spirit of her creator.

4.2 Sample SBS Theater Scenography

The purpose of *L'ange Carasuelo company* SBS work is to make possible a shared experience between scientists, artists, technicians, and audience. One of its goals is to propose a shared and simple "shadow tool" for artistic and educative purposes, considering that many performance artists, technicians, and citizens find digital technologies challenging as creative tools whereas they are commonly used for entertainment (e.g. video-games).

This work in strongly related with the deep meaning of the shadow, as a connection between us, our "invisible world", and the real world. Based on this assumption, the research started from a corpus of texts and representations from Carl Jung's work, recent digital shadow works mentioned in Section 2, and Haruki Murakami's novels. This ternary relationship had important consequences on the use of the platform, both for artistic and mediation approaches.

Firstly, writing with (and somehow, for) the tool implied a shift in the roles of each member in the artistic team. Artists had to be able to deal with technical constraints for performance design, and technicians had to understand the artistic needs, and propose "on the fly" some simple, fast, and efficient digital environments. Secondly, shadow was used to inform the audience and the performer of the space and time structure of the virtual world, by shifting our point of view on the world, offering an open gate to our own imagination. As detailed in the next section, the digital shadow played the role of an avatar that could enlarge the consequences of our motions in an immersive context. This point was particularly meaningful during the workshops we organized at the *ESSEC Business* School, hosting physically and sensorially handicapped students.

4.2.1 Technical constraints and believability

The first appropriation of the platform was to organize workshops, brain-storming, and discussions with the partners. Thanks to the artistic collaborative company *didacalie.net* and to the efforts made jointly by the artistic and technical participants, we designed *Tolalusulo*[18], a workable version of the tool that could be used to experiment various scenographic setups based on different configurations of the tracking and projection surfaces. We finally chose a frontal installation such as the one described in Figure 3 integrating: an IR translucent screen for vertical projection, a shiny floor to reflect the IR light behind the feet so that the IR camera in front the screen could catch the whole silhouette of the performers, a video-projector, and a set of theatre spotlights equipped with visible light filters installed behind the screen.

The main trouble we had to face was that our setup was shrinking the space in which the participants could perform. Restricted to one meter away from the screen, this narrow stage band was constraining the actor to a kind of 2.5-dimensional space. As a consequence we decided to write the show with this constraint: our characters would be enclosed in his space, and their shadows would deploy in a 3D space behind the screen. A kind of unconscious personal space was suddenly revealed by their independent shadows. In this way, the 2.5D performing space was expanded to a much larger world (3D space plus time, with the possibility of going back in time) through 2D shadows. Since we could not use traditional spotlights on the performers, we decided to keep the performers in the dark and to swap the roles: darken the actor, while lighting up her (digital) shadow.

These constraints, combined with a time delay through software recording capabilities, became the main ingredients of a story we wrote on stage. A text was written by *Benoît Lahoz* based on Haruki Murakami's novels, and the opening nights took place in *L'apostrophe, Cergy* and *Le Cube, Issy-les-Moulineaux* during Winter 2011 (Figure 8.e). Working with the platform impacted significantly our writing practices, and oriented us toward a layer-based compositing style. The story turned into a journey into layers of memories and social data received by the characters, in which the shadow was a kind of guide and a support for letting them reveal their deep personal values.

SBS was also used as an interactor with virtual objects like a 3D moving wall, a 2D fluid wallpaper, etc. Both the shadow as a self-representation and as an interactor were tightly coupled to make it understandable by the audience. In some scenes, the shadow was projected onto a 3D virtual world used as a stage background. Opening a 3D world to the shadow had to be believable for both the performer and the audience so that it could be perceived as a projection into a fragile Augmented Virtuality environment.

Believability was also a major issue in the experimentation workshops with pupils, students, and individuals (January 2010-June 2011). Early 2010, the major negative comment on SBS setup was about latency. The 6-year old pupils were the most concerned by this issue. In 2011 we reached approximately 30 frames per second and reduced so much the latency that it became almost imperceptible, although still

[18] http://www.didascalie.net/tolalusulo

Figure 8: *Taverny* workshops, 2010, and *Un petit à côté du monde* play, 2011.

noticed by the performers. This persistent observation unlocked another interpretation of the participants: What is actually important is not a merge between our cast shadow and the projected shadow, but the possibility for a performer to identify herself with her own shadow. As soon as we can identify ourselves with the projected black shape, all possible distortions can be applied without cancelling this personal identification. This consideration opened a very large way for dramatic experimentations: What is happening, in what kind of world, between the moment I move and the moment my shadow moves?

4.2.2 Shadow deconstruction

The first intention for the performance was to open a visual space-time to be experimented with on stage, both by the characters and the audience. It was based on shadow spatial deconstruction by casting it on diversely oriented volumes, and on temporal deconstruction through latency rendering that would result in time-inconsistent shadow. Our hypothesis was: as the character (then the audience) focuses on her shadow, she provisionally breaks her so-called unity to enter a deeper space-time of dreams, memories, and information structures. This assumption is related to the concept of theater that opens a space-time window inside the audience's own chronology, in which the spectator explores her own personality through identification and catharsis. Our research focused on Carl Jung's work on shadow, "collective unconscious" and "metaphysical reality".

By dealing with technology we played with four dimensions (3D space + time) to enter this particular world. The two main tools were: mapping the SBS on a 3D based virtual space, and increasing or decreasing the latency while performing. Thus the performer was informed of her presence in this world through her shadow, by travelling a space larger than the stage (corresponding to a specific mental space) in a deconstructed time: delaying the past while allowing the audience to catch a glimpse of the future.

The complex relationship between light source, projection surface, and obstacle made the shadow take a difficult to grasp piecewise pass (like when our shadow is cast on perpendicular surfaces and broken into scattered pieces). Consequently, the shadow cast on the "walls" of this virtual space had to be made in a realistic manner to look believable. As the scenery had to be portable, we used a procedural process to map the shadow image on a virtual space (as described by Jacquemin et al. [5]). These constraints revealed a parallel between the technological problems we had to resolve and the inner questions of the performance similar to the issues raised by Sheppard et al. in [10] on the way a dance performance can be staged in a very technological telepresence environment.

Our deconstructed character, receiving information from too many sources, was about to travel in a virtual world deconstructed in space and time. Layers of information were represented by vertically and horizontally controllable perpendicular surfaces on which the cast shadow revealed prerecorded pictures, videos, and structures (especially Rutt/-Etra-like heightfields), and then zoomed to other spaces.

By opening virtual spaces, we took the risk to make the performer disappear by not being strong enough to inhabit and "dominate" the virtual environment. To do so the performer had to enter in a genuine relationship with the shadow: she had to keep in mind what she made one second ago and then react by inventing another continuity while performing inside the moving space. Through this process the technology became a tool for improvisation: the performer, with the help and creativity of the technicians playing live, was able to inform herself of what she was doing and of the consequences of these acts in an oscillating time. Ultimately immobility suddenly closed the spaces and stopped the time, in a kind of rhythmic ritual experience, not so far of the origins of theater.

4.2.3 Shadow plays

Based on these issues, we built a few games for workshops with children and teen-agers:

- The *Shadow Phone* in which 4 participants were playing the "mirror game" with their own shadow before we shuffled the shadow videos so they could play live with someone else's shadow (Figures 8.b & c).

- The *Shadow Ballet* in which 6 video-captures of dancing children were buffered and projected as shadow silhouettes with various delays in different colors on a picture or video background. It ended up into a *dance floor of the past moment* in which each child tried to recognize the shadows' owners (Figure 8.d).

- In *What is inside my shadow*, the children were prompted to use their shadow to reveal a picture or video they had chosen, and comment on it aloud while making it visible.

- *My image that belongs to us* proposed to the participants to create a collective image with their own shadow in a sequential manner, each of them leaving a trace of their presence on the screen.

- *Shadow Pong* was an adaptation of the well-known Pong game that could be played by 2 participants using their shadow as interactor.

Other games were implemented with motion freezing, horizontal shadow flipping, buffering, inverting colors, etc., always associated with a debriefing and observation time.

The imagination and creative skills of the participants were practiced with their whole body, so that the interface with the virtual world was not reduced to a limited device such as a joystick or a Wiimote. The whole body was used to make the members of the audience understand the continuity between us, our shadow, and the virtual world, and make them feel projected into their own "shadow world" (imagination, unconsciousness, etc.).

Working with people who have physical, linguistic, or perceptive disabilities, far from limiting the possibilities multiplied them. For example, a partially-blind student passed long hours drawing the background of a platform game, and then used the shadow as an avatar. In this way his whole body (and not only his eyes or fingers) was involved into the game. Time latency was staged with students suffering from dyspraxia who were actually experiencing a latency between stimuli reception and processing. This correspondence between the real human and the virtual shadow resulted in interesting discussions with the participants and offered us some drama material for the theater play we were building together: What is happening during this transitional time? Is the time of imagination, fiction, and poetry?

Perceptive amplification was the main issue in this collective experience. In sharing this tool, we acquired knowledge and competences that led our artistic research to new unexplored paths that we could never have found just on our own. This was made possible thanks to the partnership between scientists, artists, education and civil society staff, and individuals.

4.3 Art/science collaboration process

The realization of the software platform and its use for performances and pedagogical workshops shows how scientific and technological works intertwine with artistic creation and offer new perspectives for both disciplines.

The first intuition shared by scientists, engineers and artists in their collaborative project was to use the shadow to build a bridge between real and virtual worlds. We already said that by covering a space the shadow gives a proof of presence. This is not easy to fully understand (children do it only around five years old), but it is playful to experiment. Playing with the shadow of a performer or an onlooker results in new interactions setup between the real and virtual worlds. Starting from a digital shadow, we imagined concrete artistic situations to physically interact with digital augmentation of the physical world.

The first point was that building a digital shadow was a very difficult step either for scientists and engineers or for artists and scene directors. The use of visible and invisible lights, video-projector, camera, computer, and projection surfaces, the spatial relationship between the performer/onlooker and her shadow resulted in a complex experimental environment. Finally, the scientific methodology was of a great help to decompose the complexity and to choose the appropriate setups. An amazing result was that the computer program does not grasp the concept of shadow. What a child's brain can do in one second is unachievable by the most powerful computer. Consequently the whole staff (scientific, technical or artistic) had to make common choice to build the digital shadow and to accept limitations in its use: we shared a common object, built it from scratch, and learned together, step by step, how to use it in an augmented environment.

The art/science collaboration process refutes the notion of progress and implements well a post-modernist approach to life in which errors and bugs, practices and habits, meaning and concepts count more than technological achievements and scientific advances. As a consequence, such a collaboration can only mature if both parts collaborate in an empathic and listening manner, and accept to dismiss their preconceived views on technological art. Such a need is well illustrated by Sheppard et al. in [10] in the TED tele-immersive dance environment experience, in which bugs, delays, and discrepancies are used as artistic tools, shifting from an approach where they should be avoided to a set-up in which they are integrated and controlled by the dancers.

At the beginning of our collaboration, performers played with the digital shadow as an additional character, and explored its autonomy. They imagined scenes that induced specific scientific or technological explorations to make possible interactions. Conversely, the scientists and engineers explored "by themselves" interesting properties of the digital shadows that had aesthetic qualities, and brought original set-ups to artists. For instance, tracking and particle effects were suggested by artists, but water and fire effects came from an scientific exploration of the particle engine applied to distort the digital shadow. To have built together a common object allowed independent creativity from each participant and genuine investigation producing relevant results in each field (scientific publication or shows), and finally helped to reach new territories of collaboration.

This process took several months before being mature. It was not planned when the collaboration started. We regularly used to express the need of a common vocabulary to understand the multiple and seemingly divergent emerging points of view. But the success in collaboration came from fully sharing a common object and its setups, a digital shadow interacting with a virtual world in an augmented environment. As we wrote in part 2, there are two main setups for dealing with shadows: CSBS and SBS. We just explained why we first explored the SBS. Nevertheless, current developments are actually led by the scientific partner who convinced his artistic partners to explore the CSBS by developing the potentialities of the little more tamed digital shadow. The initial exploration of the autonomous shadow, and the consequent common experience, can apply now to other contexts in which a cast-shadow can be transformed from inside. New artistic ideas will come from forthcoming workshops inv olving light designers, stage directors, and scientists. We hope to produce some works that will develop the digital part of the CSBS framework.

In our project, the shadow theme took a shape that allowed to produce in the same time scientific knowledge and artistic experiments. We were certainly helped by the original double nature of the shadow: it played a important part in the discovery of our world (principally in astronomy and in cognition as shown by Casati [3]), and it was for all time a favored mean to tell stories. Using it to explore Augmented Reality gave us the opportunity to find out new topics of research and practice.

4.4 Artistic dissemination and sustainability

Working with technologies inside a collective project made us question the economic aspects of project: How could we share the results and the tool when the project is finished? We had to find affordable solutions to install a basic software suite and consider the best low-cost "tool quality-sharing opportunities". Incidentally or not, these three aspects of our approach (technical, psychological, and social) were always tightly linked to our artistic experiments with SBS digital shadow on-stage. The necessity to share a common object brings the scientific and technical partners to organize the software platform introduced in Section 3 through shader modules that can be easily used to build by-product softwares suiting artistic needs. When compared with previous ad-hoc in-house approaches, it offers major improvements in the quality of shadow extraction for artistic design, and makes new configurations accessible for pedagogical workshops with pupils. The GPU-based approac h to digital shadowing of the research team made this porting possible and opened the door to many additional special effects. We used SBS as a representation of a semi-dependent shadow of the performers, enhanced with time delay, frame buffering, and distortion effects. Blending modes between distinct effects were, in this case, very useful to deconstruct the shadow and make it enter in the digital world of the video.

Each involved artist proposed numerous, various and specific experiments to allow pupils and audience to play with their own shadows and discover a wide variety of creative worlds. This creativity was also shared by librarians who brought their own proposals to feed workshops with references and activities about shadows. We also shared our new skills with other dance and theater companies. Taking apart the financial aspects, the cost of working with technologies introduces a new parameter of power in the arts world depending on how knowledgeable the people are with the technology. A way for helping to overcome these power issues is to make clearer the technological dependencies between partners. It makes networking possible and results in stronger collaborations. We tried to find the most affordable hardware and software solutions for the platform in connection with a wide art-activist community including free software developers. And two companies used *Tolalusulo* to work with digital shadows: Anne Morel and Sans Titre Production deal with gender themes in two recent shows. Christophe Greilsammer and L'Astrolabe Cie created a performance from the famous Andersen's tale *The Shadow*. This collaboration process produces a state of mind in the use of shadows that arguably results in a new type of exchange with the audience and with "external" artists.

5. CONCLUSION AND PERSPECTIVES

The success of the workshops leads the artists to think about simplified derived setups on common hardware and software to broadly disseminate the creative and pedagogical tools. A designer will make improvements in this direction. Moreover, numerous interactions already developed in the platform by engineers and scientists offer exciting perspectives to create new stories and performances.

Playing with the shadows implied a close relationship between the performer and a screen. Attempts have been made to break the flatness of the screen by using a 3D world in which shadows were walking around. This can surely be developed with 3D stereoscopic projections. But an alternative has been suggested by the scientific team to deeper explore the possibilities offered by CSBS in interactive environments using traditional lighting. This exploration will be a future development of the current project, involving in addition both a space designer and a light designer.

By demystifying the digital aspect of the work and focusing on the meaning in the art piece (even if working with technologies) our new practice entails necessary changes in our beliefs to be successful.

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