DigitalBeing: An Ambient Intelligence Interactive Dance Experience

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Abstract

This chapter seeks to explore the development of an ambient intelligent dance space. In particular, the chapter proposes intelligent systems that use non-linear optimization as well as symbolic rule-based systems to adjust sound/music, on-stage lighting, and projected visual imagery in terms of movement and color to dynamically reflecting the dancer's arousal state measured through physiological sensors worn by the dancers. To aesthetically adjust physical lighting around the dancers, dancer's location will need to be identified. This variable will be identified using pressure sensor mats installed on the floor to track dancers' movements. Data from these sensors will be passed into a three layered architecture. Layer 1 is composed of a sensor analysis system that analyzes and synthesizes physiological and pressure sensor signals. Layer 2 is composed of intelligent systems that adapt lighting, sound/music, and visual imagery in terms of pacing and colors to portray the dancer's arousal state. The intelligent physical lighting system dynamically adjusts physical lighting color. The intelligent sound/music system dynamically and unobtrusively adjusts the music/sound in the space. The virtual projected imagery will be created using a cellular automata system that will be intelligently manipulated in terms of cell colors to reflect the arousal state and position of the dancer. Layer 3 translates the high-level adjustments made by the intelligent systems in layer 2 to appropriate lighting board and audio box commands. Using this architecture we seek to extend the mode of dance expression offering a space that performance artists can use as a creative tool that extends the

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grammar of dance. In this chapter, we will describe this architecture in detail as well as the equipment, control systems, and Artificial Intelligence algorithms used.

8.1 Introduction

Nowadays it is hard to visualize a space devoid of technology. Walking around in the city, you see people on their cellphones, PDAs, Laptops, etc., reading emails, chatting, or working. With such a massive shift towards technology everywhere around us, we are starting to look further into the vision of an ambient intelligent environment – an environment that integrates concepts ranging from ubiquitous computing to Artificial Intelligence (AI). In an Ambient Intelligent environment (Vasilakos & Pedrycz, 2006), people are surrounded with networks of embedded intelligent devices that can sense their state, anticipate, and perhaps adapt to their needs. What does such a vision entail for performance and art? How would we experience art installations, dance performance, theatre, and film? Although we will always enjoy the way theatre plays and dance performance is conducted today, we believe with the birth of ambient intelligence, we can explore new aesthetic spaces that we didn't explore before. This chapter focuses on addressing the design of such an ambient intelligent environment specifically to explore interactive dance as a space for experiencing a new aesthetical dimension for dance.

Since time immemorial humans have attempted to graphically represent themselves to themselves in the belief that this visual externalization of their physical and/or psychological being may help them grasp who, what, why, and how they are. The prehistoric cave paintings, the history of portraits and masks, medical imagery, surrealism, and lately cyberspace avatars are all representational attempts with the same origin. Scanning such imagery across time, space, and cultures reveal a wide range of visual metaphors for expressing identity and life. And yet, despite their diversity, they all sooner or later, directly or indirectly refer back to the body as their foundation and inspiration.

Dance is an art of expression. When a dancer walks on stage, she captures the audiences' attention through her smooth and/or sharp movements and gestures reflecting her interpretation of the music in space. Dancers have been trained to use their bodies to express their inner feelings while improvising with music. Theatre dance extended the forms of dance expression by adding lighting and scenery. Similarly, we aim to extend the current forms of expression used in dance through the use of intelligent systems that adapt physical lighting and projected imagery as well as sound/music to reflect the dancer's arousal state measured through physiological sensors. The resulting artifact is the *DigitalBeing* – a personal signature of the dancer in digital space.

The goal of the proposed work in this chapter is to design, build, and perform an interactive *DigitalBeing* in virtual and physical space. The project explores the visual depiction of the self and the body in the light of the arising new technologies and media. The focus is the graphic representation of a "becoming self", that is, the creative expression of being in time. The artificial representation of self is generated by transforming actual physiological signals from a human body into visual and audio forms. Since the resulting form will represent the individual whose biological signals generate and sustain it, it will be a personal signature of that individual in digital space. The *DigitalBeing* will envelop its user via projection as well as physical stage lighting technologies and sound/music so that they are able to visualize, materialize, inhabit, and interact with their own self immersively. By offering a new way of expressing human life, the *DigitalBeing* will provoke profound and lasting aesthetic and reflective responses from its users/audience. Based on this experience and further work, the *DigitalBeing* will be developed into an interactive public installation to be displayed at selected regional and national art venues. The pursuit of this project is expected to establish a new area of creative inquiry in dance with several potential spin-offs and artistic collaborations.

The *DigitalBeing* obtains its raw materials from a set of non-obtrusive and integrated physiological sensors embedded in an Ambient Intelligent dance environment. Dancers will wear wireless physiological sensors that measure three functions: 1) skin conductance, 2) cardiac activity, and 3) body temperature. In addition, we will install pressure sensors in the physical dance floor. The physiological data as well as pressure signals will be analyzed synthesizing the dancer's arousal state and identifying on-stage lights affecting the dancer, respectively. This information will then be distributed to three systems: an intelligent on-stage lighting system, a cellular automata system, and an intelligent sound/music system. The intelligent lighting system use non-constraint optimization to adjust lighting color and layout reflecting the dancers' arousal state while maintaining projected style and other lighting goals. The cellular automata system will manipulate cell colors and movement of 2D cells projected on the backdrop. The intelligent sound/music system is developed based on rule-based systems to dynamically and unobtrusively adapt the sound/music to the current dancer's arousal state given authored rules and sound/music layers. Artists will supply the sound/music to be projected. Additionally, artists will also encode high-level directions indicating the style of lighting movement, changes in projected visual imagery, and music changes.

The *DigitalBeing* not only assures its creative uniqueness but also opens untapped opportunities. The use of the body to drive audio and visual events is not new in the contemporary performing arts addressing electronic environments. However, previous works have been constrained by choreographic strategies, limited or no changes to the physical environment, or no use of participant's internal states. Producing and performing the *DigitalBeing* offers a new type of performance. Given its uniqueness (i.e., there is no precedent of this kind of work) the *DigitalBeing* presents numerous artistic, design, computing, media, and conceptual challenges. This demands major interdisciplinary collaborations among the Arts (Choreography, Modern Dance, and Music), the Sciences, and the Technology (Bioengineering, Medicine and Computer Science) disciplines.

In this chapter, we will discuss *DigitalBeing* in more detail. We will first discuss previous work in the area of interactive dance. We will follow this discussion with a discussion of the artistic direction we decided to take for the first prototype of this system. We will then discuss in detail the proposed ambient intelligent system describing the sensors, the intelligent systems, and the utility of the system in extending the expressive potential of dancers within a dance space. We then describe a current prototype of the system. We will conclude by discussing limitations and future work.

8.2 Previous Work

Numerous composers, choreographers, dancers, and theorists have explored the use of technology in theatre and dance. We do not intend to describe all the work that has been done in the realms of academic research, installations, or interactive productions here. However, we will discuss few examples that have influenced our work. Discussing these examples will situate our work, uncover its uniqueness, and its purpose.

One of the most influential and significant work that used animated figures for choreography is the work of Merce Cunningham. In his dance performance Trackers, he used a computer system called Life Forms devised by Tom Calvert (Calvert & Mah, 1996) to choreograph his dance movements. Life Forms is a piece of software designed to provide several stylized animated characters that allow users to create a dance choreography or explore certain steps. In addition to using animation for choreography, Cunningham also developed a virtual dance installation in collaboration with Paul Kaiser and Shelley Eshkar, which was presented at Siggraph 1998. This installation was composed of a mental landscape in which motion-captured hand-drawn figures performed intricate choreography in 3D (Cunningham, Kaiser, & Eshkar, 1998).

Besides the use of animated characters in a virtual performance, several performers have explored the use of animation within a real-life dance performance. For example, projected graphics have been used on backdrops in the San Francisco ballet Pixellage (Crow & Csuri, 1985). In one of the scenes they used a virtual animated ball (projected on the screen behind the dancers) which dancers threw to each other. Another ballet performance called The Catherine Wheel (Gruen, 1983) used an animated character to represent the spiritual figure of Saint Catherine. By using an animated character, artists can easily represent the spiritual nature of the character as opposed to using real life effects or make-up.

Another example of the mix between virtual and real characters is depicted in the work of Meador et al. (Meador, Rogers, O'Neal, Kurt, & Cunningham, 2004). They developed a collaborative production that mixes the use of virtual and real dancers within a dance stage. They used three different projectors within a dance performance; one of these projectors was used to project a virtual character that interacted with the dancers on stage (Meador et al., 2004). Their work was influenced by the work of Dan Saltz who directed The Tempest 2000 produced by the Interactive Performance Lab Group at the University of Georgia [http://dpa.ntu.ac.uk/dpa_search/result.php3?Project=136]. In this production of The Tempest, they projected the character Ariel as a virtual character. They used motion capture to animate the character in real-time. The use of a synthetic character for Ariel added to his magical quality, and thus enhanced the overall performance.

Another example of the use of technology in dance performances is the use of motion capture to inform changes in projected imagery. Troika Ranch, a Dance Company situated in New York City [http://www.troikaranch.org/], developed a motion capture system called MidiDancer, which uses several cameras to capture performers' movements. They explored the use of the MidiDancer as a method of dynamically synthesizing dancer's movements and using these synthesized movements to dynamically alter the projected video during the performance. Even though they presented several unique and interesting ideas, the use of motion capture within dance productions is still an area under research and exploration.

Ulyate and Bianciardi showed their work on the Interactive Dance Club in Siggraph 1998 (Ulyate & Bianciardi, 1998, 2001). The interactive dance club was composed of several zones where they experimented with several setups and sensors, including infra-red, pressure, and vision. They divided the dance floor into different zones which induced different interactivity paradigms. For example, in one zone they had a set of parallel light beams that detected when beams were broken. By breaking beams of light, participants could trigger 4-16 musical notes.

Similar to the Interactive Dance Club, Todd Winkler explored the use of space, gesture, and motion capture equipment for music composition (Winkler, 1995, 1997, 1998). He focused on the use of dance and space to compose electronic music. He used the Very Nervous System (VNS) (Cooper, 1995; Rokeby, 1986, 1986-1990) which is a system composed of one or two cameras that detect speed and location of dancers. He explored several methods of mapping the output data from VNS to music parameters, such as frequency, pitch, timber, etc. (Winkler, 1997). He presented two productions in the late 1998 showing his work (Winkler, 1998).

Several artists have explored the reversal problem, how to visualize music in a 2D or 3D projection used in a dance performance. Currently WinAmp and Windows Media Player both include built in algorithms that map music into 2D space using a frequency spectrum extracted from the music file (WinAmp; Windows Media Player). Wagner and Carroll developed a 3D music visualization system called DeepWave (Wagner & Carroll, 2001). DeepWave analyzes music files extracting frequency, pitch, vocals, etc. and maps them to shape, color, texture, and animations in 3D space. Through experimentation they found that vocals are best mapped to color and transparency, percussion to size and shape, and guitars and keyboards to animation. DeepWave also allows users to author skins and input 3D scenes and textures.

Beyond projection as a way to influence the dance space, Louis-Philippe Demers have explored the utility of adjusting physical stage lighting within an art installation (Demers, 1993; Demers & Jean, 1997). He developed a system that uses several sensors including, pas sensors, video sensors, optical and infrared sensors, sonar sensors, and 3D ultrasound devices to predict blocking and gather gesture information. Using these as input, he developed a system that manipulated on-stage lighting in terms of light brightness, color, and angle. He showed this system in several projects, including The Shadow Project (Crawford, Schiphorst, Gotfritt, & Demers, 1993) and Lost Referential (Demers & Vorn, 1998).

Our work will borrow and extend his technique by adding a set of AI algorithms enabling change in light direction, color, and intensity based on the dancer's arousal state; we will also base lighting manipulation on results of a qualitative study of film lighting patterns, which will be discussed in detail in a later section. In addition, we present a new aesthetic vision by enveloping the user within screen projection and on-stage lighting technologies, and thus allowing them to visualize, reflect, inhabit, and interact with themselves and others in new ways.

8.3 Artistic Vision

Dance as an art form appeared in the early Egyptian Civilization as a form of rituals used by hunters to find a prey. It then evolved into an art where professional performers danced at social events, and traveling groups danced in public squares of cities such as Thebes and Alexandria. In ancient Greece, dance was regarded as an important form of art that promotes physical health and education. During the Roman Empire, dance performances have been influenced with spectacle and mime. Through the years, dance has taken on different forms and shapes in different cultures. The emphasis, however, has always been the same: an expression of human emotions through body movements. Several dances took a free-form improvisational style; examples include African, Native American, Spanish, and Indian dances. Due to the prolific volume of dance forms that exist today and their variations, it is difficult to discuss all of them in this chapter. Thus, we will briefly outline some examples of free-form improvisational dances that have influenced our work.

There are several types of improvisational Indian dances. Most of these dances have evolved as deep religious activities. For example, Odissi dance is a dance used as a devotion to Lord Krishna. Odissi dancers use their heads, busts, and torsos in soft flowing movements to express specific moods and emotions. The Mohini attam is another form of dance used to show love and devotion to the god. In this form of dance, dancers use circular movements, delicate footsteps, and subtle expressions to express and suggest emotions.

Another form of dance that is primarily improvisational is the flamenco dance which evolved with influence from Indian and Middle Eastern dancing as well as tap dancing. Flamenco dancing is characterized with rhythmic hand movements, clapping, and tapping of the feet to express different emotions. In fact flamenco music itself consists of different beats that characterize a variety of human emotions. For example, the *Bulerias* is a form of flamenco that is festive and is used to celebrate life. In contrast *Siguiryas* is a form of flamenco music that is truly tragic expressing death, existential alienation, unrequited love, despair, desolation, and loneliness.

In addition to cultural dances, we have also looked at modern dance. Modern dance is a free-form improvisational dance developed in the early 20th century, when few dancers rebelled against the rigid constraints of classical Ballet and started practicing freeform dance. One of these dancers was Emile Jacques-Dalcroze who created a system of rhythmic gymnastics aimed at reaching a harmony between the static and dynamic forces of the human body. She believed in the creative richness of mixed media and choreographed pieces at the crossroad between dance and opera. Mary Wigman is another figure known for her influence in creating European Modern Dance in the late 1920s. In her dances, she focused on the expression of body movements that convey inner deep emotions. Decorations, costumes, and even music were unimportant in her dances.

Improvisation is a key element of the work presented in this chapter. The vision is an interactive experience that lends itself to improvisation and exploration of dance movements in space. We envision it as an interactive installation space, where professional and non-professional dancers improvise movements in an ambient intelligent space. As dancers move, projected imagery, lighting, sound, and music change to reflect the dancer's state and movements, thus allowing dancers to explore the use of dance movements to paint a story within the space.

In designing this space, we will artistically adopt a very simple abstract style for the virtual imagery as well as the sound and music. This will allow us to remove the cultural connotations in the music, sound, and visuals; thus facilitating better adaptation to the audience and participants. We also will aim to emphasize, and perhaps exaggerate if necessary, the reaction of the environment, in terms of its lighting, visual imagery, and sound/music changes. This is necessary to ensure that participants and dancers clearly see that the environment is reacting to their movements and states.

8.3.1 Projected Imagery

We envision very abstract 2D imagery used to visualize the dancer and her state. This will be similar to a previous project that one of the authors worked on called The Portal. The portal was a project developed at Northwestern University and installed in the entrance of the Block Museum. Many collaborators were involved in the inception, design, and development phases of this project. Cameras were installed in the space; computer vision techniques were used to identify participants' movements and positions, which were then used to derive changes to the abstract 2D imagery generated based on a cellular automaton algorithm. The project also used granular synthesis to drive multi-channel audio. Images from the project are shown in figure 1.

We aim to project similar simple abstract 2D representations. We are experimenting with the use of cellular automata to initiate cells whose color changes can be induced by dancer's position as well as arousal state. The specifics of the algorithm will be described in more detail in section 5.

Fig. 1. Portal Project

8.3.2 Projected Sound

In this chapter, we refer to music and sound as one entity, because artistically we see them being manipulated as one. Of course, experientially music is very different from sound. However, since we are aiming at a very abstract style composition, we are shooting for abstract sound with melodic attributes. The sounds will be composed of several layers. The intelligent system will manipulate the volume of these layers thus affecting the projected sound properties. We will discuss this system in greater detail in a later section.

8.4 Dance Space and Equipment

We envision a space where stage lights are rigged on posts. We use a backdrop to project 2D imagery. We implant pressure sensors in the dance floor to track dancers' positions and movements. We also include a 3D surround sound system to play the music composed for the performance. The dancer wears an armband that collects physiological information while she freely moves around in the space. Sensor information will be transmitted wirelessly through a local network to a computer that then analyzes this information and alters the music/sound, on-stage lighting, as well as the projected 2D imagery in terms of its color to express the dancer's arousal state and movements.

Dancers wear the SenseWear® PRO2 Armband [http://www.bodymedia.com/technology/index.jsp], which is a wearable body monitor that enables continuous collection of low-level physiological data, including heat flux, skin temperature, near body temperature, and galvanic skin response. It also includes a streaming program that we use to continuously and wirelessly stream the physiological data to a PC for processing while dancers freely move in space.

The choice of this particular device was made due to our experience with it. After experimentation with several devices, we found that this device is particularly reliable when participants are engaged in athletic activities. We have tested this device and have confirmed that it can be used to derive a clear indication of the dancer's arousal state but not emotional state. Predicting emotional states is unfeasible using physiological sensors alone, additional information is required, such as postures, gestures, and facial expressions extracted through high resolution cameras. In this phase, our goal is to extract and identify dancer's arousal state rather than emotional state, and thus the body media device suffices for our purposes.

We adopt a pressure mat composed of many smaller pressure sensor mats, similar in design to the one developed by Srinivasan et al. (Srinivasan, Birchfield, Qian, & Kidane, 2005); an example can be seen in figure 2. As shown the device is interfaced to a micro controller. This pressure sensor mat is designed as an on-off switch, and thus is good for determining if a person stepped on the mat. We will use several mats to cover the dance floor. Signals from these sensors are sent directly to a host computer that assembles and identifies light IDs for lights on the stage affecting the dancer.

As with any performance, artistic content is important. Artistic content for this particular piece include: (1) set of parameters indicating the value of change in color of the virtual projected imagery as a function of dancer's

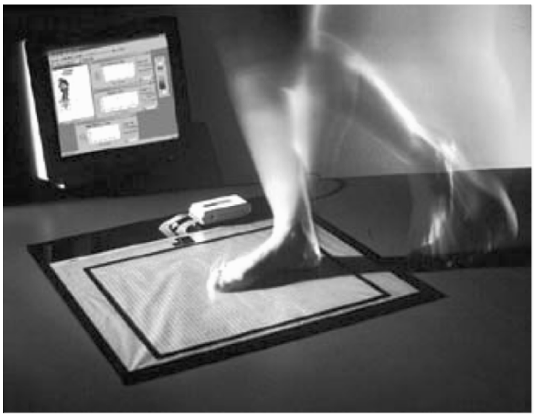

Fig. 2. An example pressure pad

arousal state, (2) set of parameters indicating the change of light patterns in the physical environment as a function of physiological measurements and dancer's location, (3) the sound and music piece composed for the performance, and (4) rules indicating how sound/music changes as induced by the dancer's movements and arousal state. As we discuss the intelligent systems, we will also discuss the tools that are included with every system allowing artists to input stylistic constraints to direct the lighting and music changes within the interactive experience. The specific details of artistic specified directions will be discussed in detail.

8.5 Architecture

The architecture is composed of several subsystems (shown in figure 3). The Sensor Analysis System analyzes two sensor signals: physiological sensor signals formulating the dancer's arousal state, and pressure sensor signals identifying lights relevant to the dancer's positions. The arousal state is stored in a structure called Dancer Arousal State represented in XML. The lights relevant to dancer's positions are stored as a list of light IDs that continuously change as dancers move.

The Dancer Arousal State structure is passed to three systems: 2D Imagery System, Intelligent on-stage Lighting System, and Intelligent Sound/Music System. The intelligent Sound/Music System manipulates the sound/music by dynamically adjusting low-level properties of the layers of the composed sound/music based on the dancer's arousal level and authored rules. The intelligent on-stage lighting system determines colors and angles for stage lights

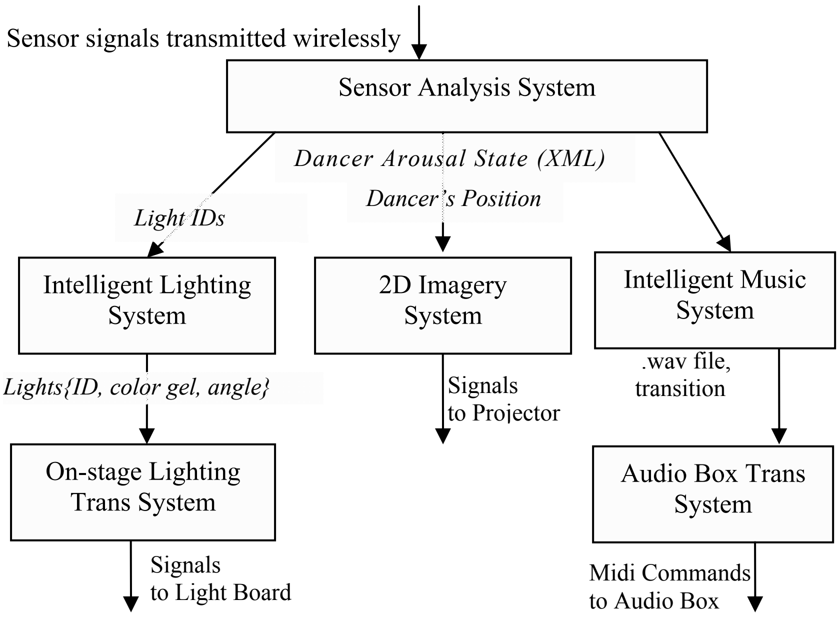

Fig. 3. Architecture of the System

given the light IDs of lights affecting the dancer, the dancer's arousal state, and artistic constraints dictating stylistic lighting parameters. It categories lights on stage as: focus lights which are lights affecting the dancers given by the list of light IDs (output of Sensor Analysis System), and non-focus lights, all lights not in the list of light IDs. Based on this it calculates colors and angles for each light specified in the light setup. These values are calculated based on the dancer's arousal state using theatre and film lighting design theory (Alton, 1995; Birn, 2000; Block, 2001; Gillette, 1998), as will be discussed below. For each physical on-stage light, the system identifies a color represented in RGB and an angle rotation. This information is then translated to light board hex code by the On-stage Lighting Trans System.

8.5.1 Sensor Analysis System

Using the physiological sensors discussed in section 3, we collect GSR (Galvanic Skin Response) and body temperature. These signals are continuous numerical values. We pass these signals through a filter and synchronize their readings and sampling rates. The output of this system is a continuous function describing arousal in time increments, where the sampling rate is the max of all sampling rates of the used sensors.

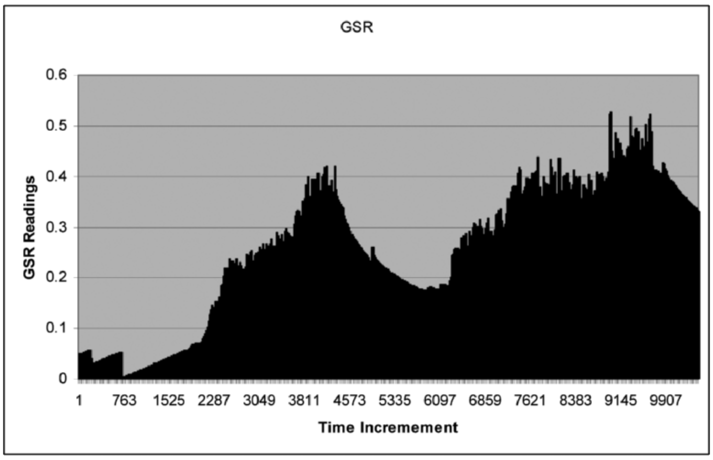

Fig. 4. GSR reading while dancing for a 45-minute segment

An example GSR reading from a dance performance that lasted 45 minutes is shown in figure 4. As shown, the GSR readings follow the intensity in the performance. The peaks of the graph depict fast intense movements. This graph is then smoothened; the resultant signal is passed to the intelligent systems.

Gathering blocking information is important to allow more intelligent lighting changes and setup, e.g., composing lights to focus on the dancer. At preproduction, we manually map lights to specific mat numbers. Receiving pressure signals from a specific mat indicates that a person has stepped on the mat. Therefore, instead of gathering or mapping 3D positions, we pass dancer position as a mat number(s). Using the lights-to-mat mapping, we determine which lights impact the dancer at any particular moment in time. The output of this system is a list of light IDs of lights affecting the dancer at the specific moment in time. Since this particular output is continuously changing, its output is buffered and fed to the next layer for processing as a process within the next layer becomes available.

8.5.2 Expressing Arousal Through Lighting

8.5.2.1 Lighting Patterns for Expressing Arousal – Based on Film and Theatre Lighting Theory

Films and theatre productions use several color and lighting techniques to parallel and support the dramatic intensity expressed in the narrative (Birn, 2000; Block, 2001; Bordwell & Thompson, 2001; Brown, 1996; Calahan, 1996; Cheshire & Knopf, 1979; Crowther, 1989; Gillette, 1998). The specific effects or colors used for expressing emotions vary. For example, some shows use warm colors to signify positive emotions and cool colors to signify negative emotions; other shows use an opposite pattern. We believe that the actual link between emotions and color is ambiguous and may vary with culture.

In this section, we concentrate on discussing several contrast and affinity patterns that are used to evoke or parallel tension. We formulated these patterns based on a qualitative study of over thirty movies, including Equilibrium, Shakespeare in Love, Citizen Kane, The Matrix, and The Cook, The Thief, His Wife and Her Lover. According to our study, the techniques used can be divided into shot-based color techniques: color techniques used in one shot, and scene-based color techniques: techniques used on a sequence of shots.

An example shot-based color technique is the use of high brightness contrast in one shot. Brightness contrast is a term we use to denote the difference between brightness of different areas in the scene. High brightness contrast denotes high difference between brightness in one or two areas in a shot and the rest of the shot. This effect is not new; it was used in paintings during the Baroque era and was termed Chiaroscuro which is an Italian word meaning light and dark. An example composition can be seen in Giovanni Baglione's painting Sacred love versus profane love shown in figure 5. This kind of composition is used in many movies to increase arousal. Perhaps the most well known examples of movies that use this kind of effect are film noir movies (shown in figure 6), e.g. Citizen Kane, **The Shanghai Gesture, This Gun for Hire.** Another form of contrast used in movies is the contrast between warm and cool colors (Block, 2001). Several movies use a high warm/cool color contrast composition, where contrast is defined as the difference between warm colored lights lighting the character and cool colored lights lighting the background. These kinds of patterns are usually used in peak moments in a movie, such as turning points. Lower contrast compositions often precede these heightened shots, thus developing another form of contrast, contrast between shots.

In addition to color and brightness contrast, filmmakers also used affinity of color, e.g. affinity of high saturated warm colors or unsaturated cold colors in one shot (Birn, 2000; Block, 2001; Bordwell & Thompson, 2001; Brown, 1996; Calahan, 1996; Cheshire & Knopf, 1979; Crowther, 1989; Gillette, 1998). An example movie that extensively used this technique is The Cook, the thief, his wife, and her lover. Other examples include The English Patient, which used affinity of de-saturated colors, and Equilibrium, which used affinity of cold unsaturated colors.

Fig. 5. Chiaroscuro Technique used in Sacred love versus profane love Painting

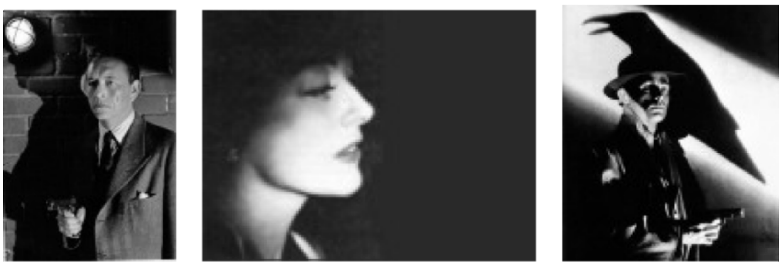

Fig. 6. Film Noir uses contrasts and shadows

The perception of contrast, saturation, and warmth of color of any shot within a continuous movie depends on colors used in the preceding shots. Also, the process by which color is used to evoke or project dramatic intensity depend on the sequence and temporal ordering of the effects discussed above. For this purpose, we define our patterns in terms of techniques spanning time over several shots.

The first technique we discuss is the use of affinity of saturated colors for a period of time. Movies, such as The Cook, the thief, his wife, and her lover, sustained affinity of highly saturated warm colors for a period of time. We believe that the temporal factor is key to the effect of this approach; this is due to the nature of the eye. The eye tries to balance the projected color to achieve white color. Hence, when projected with red color, the eye will try to compensate the red with cyan to achieve white color. This causes eye fatigue, which in turn affects the participant's stress level, thus affecting arousal.

In contrast to the use of affinity, several movies used contrast between shots to evoke arousal (Alton, 1995; Block, 2001). For instance, filmmakers used warm saturated colors in one shot then cool saturated colors in the other, thus forming a warm/cool color contrast between shots to reflect a decrease in dramatic intensity. Some designers use saturated colored shots then de-saturated colored shots creating a contrast in terms of saturation; example films that used this technique include Equilibrium and The English Patient. Based on these observations, we identify the following patterns:

Pattern No.	Description
I	Subjecting audience to affinity of high saturated colors (where high saturation ranges from 70% to 100%) for some time increases arousal
II	Subjecting audience to contrast in terms of high saturated then low saturated colors (where saturation ranges from 100% to 10%) over a sequence of shots decrease arousal
III	Subjecting audience to contrast in terms of low saturated then high saturated colors (where saturation ranges from 10% to 100%) over a sequence of shots increase arousal
IV	Subjecting audience to contrast in terms of high brightness then low brightness (where brightness ranges from 100% to 10%) over a sequence of shots increase arousal
V	Subjecting audience to contrast in terms of low brightness then high brightness (where brightness ranges from 10% to 100%) over a sequence of shots decrease arousal
VI	Subjecting audience to contrast in terms of warmth then cool colors (where warmth ranges from 100% to 10%) over a sequence of shots decrease arousal
VII	Subjecting audience to contrast in terms of cool then warm colors (where warmth ranges from 10% to 100%) over a sequence of shots increase arousal
VIII	Subjecting audience to increase of brightness contrast subjected in a shot (where brightness contrast is measured in terms of difference between bright and dark spots in an image) over a sequence of shots increases arousal

IX	Subjecting audience to decrease of brightness contrast subjected in a shot (where brightness contrast is measured in terms of difference between bright and dark spots in an image) over a sequence of shots decrease arousal
X	Subjecting audience to increase of warmth/cool color contrast subjected in a shot (where contrast is measured in terms of difference between warm and cool spots in an image) over a sequence of shots increases arousal
XI	Subjecting audience to decrease of warmth/cool color contrast subjected in a shot (where contrast is measured in terms of difference between warm and cool spots in an image) over a sequence of shots decreases arousal

These patterns will be used by the intelligent lighting system to manipulate lighting in real-time to reflect a decrease or an increase in dancer's arousal state based on the current lighting state as will be discussed below.

8.5.2.2 ELE

ELE, Expressive Lighting Engine, is an automatic intelligent lighting control system developed based on cinematic and theatrical lighting design theories; it is designed to automatically select the number of lights, their positions, colors, and angles. To accomplish this task, ELE uses lighting design rules formulated based on a study of film and theatre lighting design techniques. These rules are represented mathematically in an optimization function. The use of optimization is important to balance conflicting lighting-design goals. While adjusting the lighting, ELE also maintains stylistic and artistic constraints.

ELE as a black box is illustrated in Figure 7. As shown, ELE takes in several parameters, represented as an XML structure called WAMP. These parameters are as follows:

- Stage layout or scene graph
- Locations of characters
- Local props that emit light, e.g. windows, torches, lamps
- Stylistic parameters including: low-key/high-key, desired depth value and importance or depth, desired direction, overall contrast level, overall palette, specific ideal saturation, warmth, intensity or hue values for particular areas in the level or scene
- Dramatic intensity of the scene

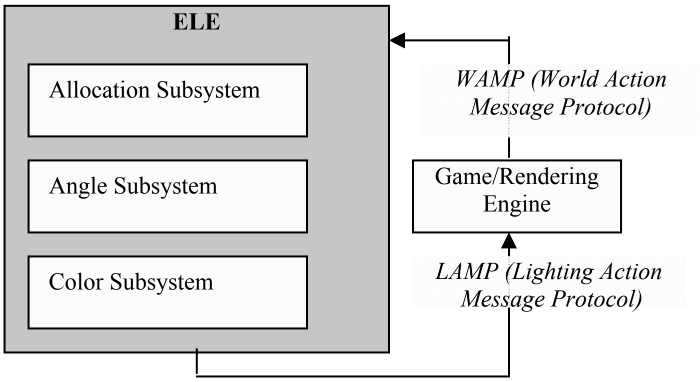

Fig. 7. ELE's Architecture

ELE then emits an XML-based structure called LAMP, which includes the following:

- Number of lights to be used.
- For each of these lights:

1. type of instrument (e.g., spot light or point light)
2. color in RGB color space
3. attenuation
4. position as a 3D point
5. orientation including the facing and up vectors
6. range
7. masking parameters
8. Depending on the light instrument used, the Penumbra and Umbra angles.

These parameters are given to a rendering engine to render the frame.

As shown in the figure, to configure the lighting in the scene ELE is divided into three subsystems: allocation subsystem used to select the number of lights and their relative location based on the areas in the scene, angle subsystem which selects angles for each light, and color subsystem which selects colors for each light. I will discuss these subsystems briefly below.

Using theatrical and cinematic lighting design theories, ELE uses stage layout or scene graph information as well as artistic stylistic constraints to device a light layout. It divides the scene into n different cylindrical areas. It then categorizes these areas as: focus, describes the focus of the scene, non-focus, areas surrounding the focus area, and background areas. This is important because lighting designers often use light to bring out the focus, increase depth by varying brightness or color of lights in different areas, or increase contrast (determined by colors of lights lighting focus and non-focus areas). ELE determines where to direct viewers' attention (or the focus) given the characters in the frame.

By taking artistic style directions considering what the artist cares about, e.g. depth, motivation, contrast, etc., ELE optimizes a multi-objective function to determine the number of lights to use for each area. The function is as follows:

$$p_{opt} = \arg\max_{p} \left(\lambda_v V(p) + \lambda_d D(p) + \lambda_m M(p) + \lambda_{vc} VC(p) \right), \qquad \text{(Eq. 1)}$$

where p is light configuration, λ_v is the importance of visibility, λ_d is the importance of depth, λ_m is the importance of modeling, and λ_{vc} is the importance of visual continuity, and where $V(p)$ is visibility given p, $D(p)$ is depth given p, $M(p)$ is modeling given p, and $VC(p)$ is visual continuity given p.

We formulated a greedy algorithm that allocates lights to each visible area in the scene, as follows:

1. each area is assigned the maximum number of lights it can have;
2. remove one light that will incur the smallest loss; and
3. repeat step 2 until the number of lights assigned is less than or equal to the maximum.

Oftentimes, artists want their lighting design to reflect realistic directions. This desire can be encoded as an artistic direction that ELE then uses to determine angle of light. In determining the angle of light, ELE also takes into account the quality of light and their influence in projecting depth, modeling, and mood. ELE uses a non-linear optimization system based on hill climbing to select an angle for each key light that minimizes the following function:

$$\lambda_v (1 - V(k,s)) + \lambda_{-} \left| k - k^{-} \right| + \lambda_m \left| k - m \right| + \lambda_l \min_i \left| k - l_i \right|, \qquad \text{(Eq. 2)}$$

where k and s are defined as the key light azimuth angle relative to the camera and the subject angle relative to the key light, respectively, as shown in figure 3, k^- is the key light azimuth angle from the previous frame, λ_- is the cost of changing the key light angle over time (to enforce visual continuity), λ_m is the cost of deviation from the mood azimuth angle, m is the mood azimuth angle suggested by the artist, λ_l is the cost of azimuth angle deviation from a practical source direction, l_i is the azimuth angle of light emitted by the practical source i, and λ_v is the cost of deviation from an orientation of light that establishes best visibility.

Based on Millerson's (Millerson, 1991) documented rules, we formulated the following equation to evaluate the visibility and modeling of a given key light azimuth angle:

$$V(k,s) = \sin(k)\cos(s). \quad \text{(Eq. 3)}$$

ELE uses rules based on Millerson's (Millerson, 1991) guidelines to select fill and backlight azimuth angles depending on the value of the key light angle. According to Millerson's guidelines (Millerson, 1991), fill light azimuth and elevation angles are calculated to be the mirror image of the key light angle. We define backlight azimuth angle as:

$$b = (k + \pi) \bmod 2\pi. \quad \text{(Eq. 4)}$$

The interaction between colors assigned for each area in a scene composes the contrast and feeling of the entire image. Using the ideal values and their associated costs, ELE uses non-linear optimization to search through a nine-dimensional space of RGB values. It differentiates among focus colors, non-focus colors, and background areas to select a color for each individual light in the scene. It evaluates this color by using a multi-objective cost function, where each objective evaluates the color against the lighting-design goals, including establishing depth, conforming to color style and constraints, paralleling dramatic tension, adhering to desired hue, saturation, and lightness, and maintaining visual continuity. The cost function is defined as follows:

$$\lambda_d \left(D(c^t) - d\right)^2 + \lambda_c \left(\text{contrast}_\phi(c^t) - \delta\right)^2 + v(x) + \sum_{i \in \{f,n,b\}} P(c_i^t, c_i^{t-1}), \quad \text{(Eq. 5)}$$

Where

$$p(c_i^t, c_i^{t-1}) = \begin{array}{l} \lambda_{s_i} \left(S(c_i^t) - s_i\right)^2 + \lambda_{h_i} \left(H(c_i^t) - h_i\right)^2 + \\ \lambda_{l_i} \left(L(c_i^t) - l_i\right)^2 + \lambda_{w_i} \left(W(c_i^t) - w_i\right)^2 + \\ \lambda_{ch} E(c_i^t, c_i^{t-1}), \end{array} \quad \text{(Eq. 6)}$$

where c^t is a vector of light colors for focus *f*, non-focus *n*, and background *b*, and areas at frame *t*. Color c_i^t is represented in RGB color space; S(*c*) denotes the saturation of color *c*; H(*c*) denotes the hue of color *c*; L(*c*) denotes lightness of color *c* (in RGB color space).

ELE uses a well-known formula for measuring color difference (Hill, 1997; Luo, 2000) as follows:

$$E = \sqrt{\left(\frac{\Delta L}{k_L S_L}\right)^2 + \left(\frac{\Delta C}{k_C S_C}\right)^2 + \left(\frac{\Delta H}{k_H S_H}\right)^2 + \Delta R}, \quad \text{(Eq. 7)}$$

where $\Delta R = R_T f(\Delta C \Delta H)$ and ΔL, ΔC, and ΔH are CIELAB metric lightness, chroma, and hue differences respectively; S_L, S_C, S_H are weighting functions for the lightness, chroma, and hue components; and k_L, k_C, k_H are parameters to be adjusted depending on model material information.

The depth, *D*(*c*), of a color vector *c* is defined as the color difference between colors lighting the background areas and those lighting other areas, formulated as follows:

$$D(c) = \sum_{b \in B} \sum_{n \in NB} E(c_b, c_n), \qquad \text{(Eq. 8)}$$

where *B* are the indices for background lights; *NB* are the indices for non-background lights; and E is the color difference defined above.

Based on the results collected by Katra and Wooten described in (Katra, 1995), we used a multiple, linear regression method to formulate color warmth in RGB color space, as follows:

$$warmth\left(\begin{bmatrix} R \\ G \\ B \end{bmatrix}\right) = \begin{bmatrix} 0.008 \\ 0.0006 \\ -0.0105 \end{bmatrix}^T \begin{bmatrix} R \\ G \\ B \end{bmatrix} - 0.422. \qquad \text{(Eq. 9)}$$

The optimization problem discussed above is a constraint-based optimization problem, where the color, *c*, is constrained to a specific space of values defined by style (e.g., realistic style restricts the values of saturation or hue). ELE uses a boundary method to bind the feasible solutions using a barrier function $v(x)$, such that $v(x) \to \infty$ as x approaches the boundary defined by the feasibility region.

Although gradient descent has major drawbacks, including occurrence of oscillations and being easily stuck in a local minimum, ELE uses gradient descent for several reasons. First, it provides a fast and simple solution. Second, a local minimum in this case is preferable because it provides a solution closer to the older one, thus ensuring visual continuity. Third, alternative methods rely on the existence of a second derivative, which is not necessarily true in this case.

8.5.2.3 Intelligent Lighting System

Given the light IDs of lights affecting the dancer (the output of the sensor analysis system), the *intelligent on-stage lighting system* computes angles of each light affecting the dancer using the same angle sub-system used in the *intelligent virtual lighting system*. The other lights on the stage are set to a default angle that creates a wash on the stage.

Using the color subsystem, the intelligent on-stage lighting system computes RGB color values of each light category based on the patterns discussed above and the dancer's arousal state. The *intelligent on-stage lighting system* categorizes lights affecting the dancer as focus lights and other lights as non-focus lights. Given this categorization, it then sends RGB color values to the appropriate lights given the lights in the light ID list given by the sensor analysis system.

The choice of color will be based on the patterns discussed in 5.2.1. These patterns can be summarized as follows:

1. Arousal increase/decrease can be mapped linearly to brightness contrast increase/decrease, where contrast is established between focus and non-focus areas, i.e. difference in brightness between colors of lights lighting focus areas and others lighting non-focus areas.
2. Arousal increase/decrease can be mapped linearly to warm/cool color contrast increase/decrease, where contrast is established between focus and non-focus areas, i.e. difference in warm and cool colors of lights lighting focus areas and others lighting non-focus areas.
3. Arousal increase/decrease can be mapped linearly to saturation affinity increase/decrease, where brightness and hue is constant.
4. Arousal increase/decrease can be mapped linearly to warmth affinity increase/decrease, where brightness and hue is constant.

Depending on artistic input indicating which pattern or style he/she desires, the intelligent lighting system will adjust light colors based on the selected pattern.

8.5.2.4 Virtual Demo of the Intelligent Lighting System

As a first prototype, we have implemented a system that translates the lighting system commands to three engines: Unreal Tournament, Ogre 3D, and WildTangent. The system accepts lighting commands from the lighting system and invokes different methods in the engines that set the lights colors.

Figure 8 and 9 show screenshots where we fabricated an arousal signal; we used patterns 1 and 3 from the list above, results of which are displayed in figures 8 and 9, respectively. Figure 8 shows a simple 3D room rendered using WildTangent, where we linearly varied brightness contrast between the focal point (center of the room) and surrounding areas. The figure shows three screenshots of the room taken at different points during the transition. Figure 9 shows a first person shooter rendered using Unreal Tournament, where we mapped saturation level to the number of enemies

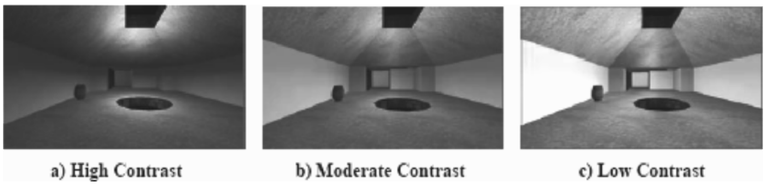

Fig. 8. Linearly increasing brightness contrast (where center of room is the focus)

Fig. 9. Linearly increasing Saturation

in the scene (i.e., if number of enemies are high the saturation is high and vise versa). The figure shows four screenshots taken at different points within the game.

As a second prototype, we have implemented the intelligent lighting system with the sensor analysis system. The sensor analysis system takes in as input the arousal signal (for this prototype we used the signal shown in figure 3), which was collected wirelessly through the body media device while one of the authors was dancing. It then created a normalized signal between values of 0-1. This signal was then passed to the intelligent virtual lighting system, which changed light layout, colors, and angles to project arousal signal as well as authored directions. In this particular prototype, the authored directions were set to allow lighting to change from warm (orange) to cool (bluish) while keeping characters within the virtual scene lit with a warm color, thus forming an increase of warm/cool color contrast as the scene progresses. We used an already pre-made environment used in an interactive story one of the authors developed called *Mirage*. The resulting lighting is shown in figure 10.

8.5.3 Expressing Arousal Through Sound/Music

Expressing arousal in music is difficult. Since our emphasis is on lighting, we will develop a simple system for improvising music; the system is similar to the work on adaptive music done by the game industry (Clark, 2001; Miller, 1997; Patterson, 2001; Ross, 2001). The basic idea is that composers will compose the improvisational piece as a set of several layers that can be manipulated by adjusting the volume associated with the layer. For

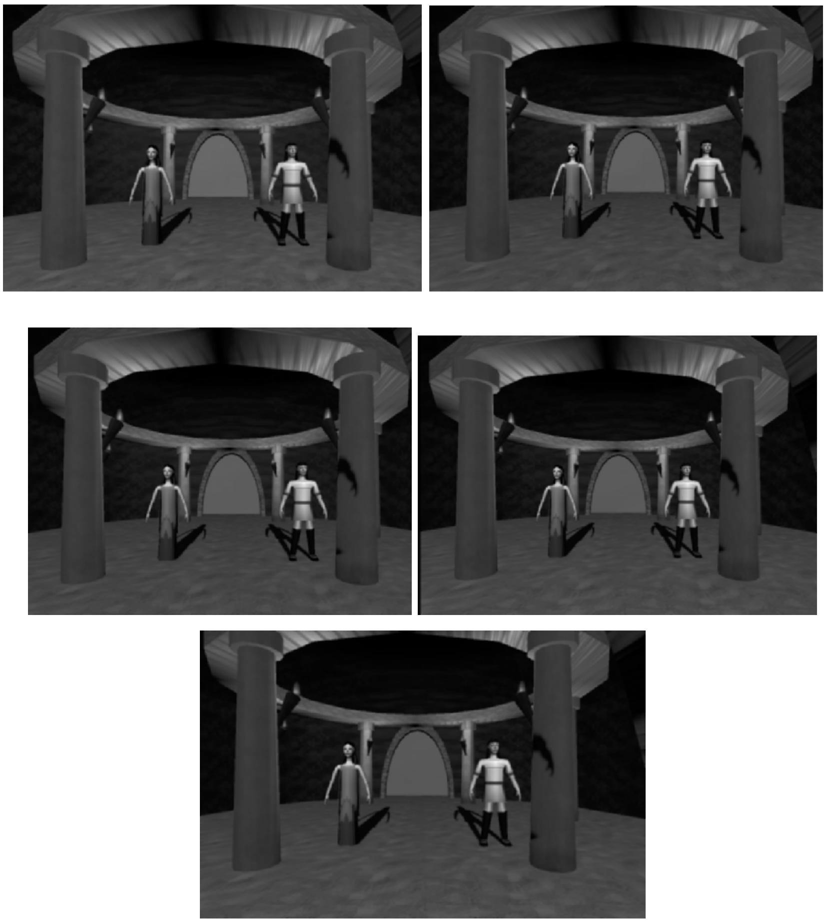

Fig. 10. Virtual Environment at various points during a virtual performance

example, composers will supply us with: a music piece composed of Layer1, Layer2, Layer3, etc. where if all layers are played, the sound will display extereme tension. Tension can then be alleviated by manipulating the volume of these layers.

They will then use fuzzy rules to denote the manipulation of the layers, e.g.

```
(def-music-tension- rule
      (      (:TRUE (volume Layer1 High))
             (:TRUE (volume Layer2 High))
             (:TRUE  (goal (Volume Layer2 Low)) )
      (:action  (assert! (decreasedby tension 10))) )
```

Where *volume* is a symbolic predicate representing the fact that Layer1 has the volume of high, and where high is a fuzzy linguistic variable describing a fuzzy state of high. This particular fact is placed in the rule-base database when the goal is to decrease volume of Layer2 to a Low state. The rule above denotes that if the Layer1 and Layer2 were played with high volume, decreasing the volume of Layer2 to Low will directly decrease the tension value by 10 increments. Using these rules the *intelligent sound/music system* will evaluate several candidate pieces given the increase/decrease of tension values and the *Dancer Arousal State* value read by the *Sensor Analysis System*. For example, if the arousal state dictates an increase of 5-7 increments in dancer's arousal then a closer increase to 5-7 increments would be the best match. The intelligent sound/music system will evaluate all candidate goals in terms of their tension value increase and will select an increase that is closer to the dancer's arousal state increase. If there are several appropriate candidates, then the system will choose one randomly. The system will select transitions in a similar manner. In order for the intelligent sound/music system to select a candidate piece given the authored pieces, it will use a rule-based system similar to the one discussed in (Forbus, 1993).

8.5.4 2D Imagery

In manipulating the 2D imagery, we are going to use cellular automata as the base algorithm for the piece. It consists of a grid of cells or pixels in this case. Each cell has 8 neighbors (4 directly beside it and 4 diagonally adjacent). Every cell has the same rule for updating, based on the values of its neighbors. Each time the rules are applied to the whole grid a new *generation* is created. One example cellular automata algorithm is the Conway's *Game of Life*, where the rules for updating neighbors are as follows:

1. Any live cell with fewer than two neighbors dies, as if by loneliness.
2. Any live cell with more than three neighbors dies, as if by overcrowding.
3. Any live cell with two or three neighbors lives, unchanged, to the next generation.
4. Any dead cell with exactly three neighbors comes to life.

We will adapt this particular method. However, we will induce several changes. First each cell will have a specific number of states indicated by its color, e.g. warmth value, saturation, and brightness. Dancer's movement will affect the cells mapped to the specific dancer's position. The color of the cell will change depending on the dancer's arousal state. This particular change will be directed by the artist. Thus, the artist can dictate that arousal will have the reverse effect on any of the 3 values of the cell color state, e.g. saturation, brightness, and warmth. Using the game of life rules, the cell will propagate its state, i.e. color, in this case, depending on the values of its neighbors.

Using these rules, we can see the effect of the dancer's movement and arousal established in the form of changes in the cells' colors. This will derive a bigger change as augmented by physical lighting changes as well.

8.5.5 Projecting Lighting and Music

8.5.5.1 Visual Imagery

In this project, we will use C++ visual studio to draw the 2D graphics. These images will be projected through a projector connected through VGA cable.

8.5.5.2 On-Stage Lighting Trans System

The output of the intelligent on-stage lighting system is: a list of light IDs, and for each light ID, an angle and a color in RGB color format. This output is passed to the *On-stage Lighting Trans system* which translates these commands to appropriate hex code commands used by the lighting board. The hex code will include routines to initiate light rotation or color commands for the appropriate lights given the output of the intelligent on-stage lighting system.

8.5.5.3 Projecting Sound/Music

As described above, the intelligent music system determines which wav files to play. Commands for manipulating volume of layers will be sent to the audio box.

8.6 Limitations

We have described an ambient intelligent environment for a dance space. Our goal is to extend the current expression modes of dance by allowing lights and projected images to change and adapt depending on dancer's movements and arousal state. By changing lighting color, direction, and lightness directly mapping the dancer's condition, we are presenting the dancer's state as a signature within the actual space. Such an interface will also allow dancers to use the environment as their expressive space and to project their own self through the environment.

We have intentionally limited the technical design to only adapt to arousal state and not emotional state. This is due to the fact that extracting or predicting emotions is still a hard and open problem. It is especially problematic because most often dancers feel an amalgam of emotions and not one particular emotion. One possible way to predict emotional states is to use a high resolution image processing algorithms to analyze facial expressions and gestures. These techniques are still under research and are generally challenged by variation in lighting conditions. Therefore using them for this project is problematic. In addition, the lighting patterns we extracted from film techniques use light and color primarily to project tension rather than actual emotions. Hence, even if we can device a method for predicting emotional states, defining lighting design patterns that can universally represent emotional states is difficult.

While few interactive theatre productions used vision to capture on-stage motion, we decided to use pressure sensors. This decision was made for several reasons. First, most vision techniques are challenged by variations in the level of illumination within the captured images. This is due to the fact that most vision techniques use pixel colors to define edges and track movement. Since we propose a performance where lighting color and angle change dynamically to reflect the arousal state of the dancers, this environment, by definition, will constitute a challenge to any vision based system. Second, privacy of dancers may be an issue for our piece. Third, we need to establish a mapping between dancers' positions and lights on stage. While we could use vision techniques to track movements, determining 3D position and its relation to lights on stage is hard.

8.7 Application and Future Work

This work attempts to design and develop an architecture that expresses the fluidity of the self/body in real time. The virtual self is generated using actual physiological signals from a human body and by transforming them into visual and audio forms in real time. Since the resulting artefact represents the individual whose biological data generate and sustain it, it is a "digital being" or personal signature of that individual in digital space. By enveloping its user through screen projection and on-stage lighting technologies, the *DigitalBeing* makes that individual visualize, inhabit, and interact with themselves and others in hitherto unimaginable ways. Participating in this new type of experience provokes profound and lasting aesthetic and reflective responses in all those involved, users or viewers.

The *DigitalBeing* not only assures its creative uniqueness but also opens untapped opportunities. Producing and performing the *DigitalBeing* offers a new type of performance that explores (a) new aesthetic conventions, rules, and techniques for visualizing the body and the self in digital space (i.e., syntax and vocabulary), (b) the relationship between design intentions, and the expectations of the performer and audience (i.e., the world of meaning: semantics), (c) how to employ and develop a design to elicit aesthetic responses (i.e., pragmatics).

We address several aesthetic questions. Can the self be expressed abstractly through virtual space? How do thoughts, emotions, and movements appear in a technologically mediated world? What is the aesthetic result of the visual interactions between real and virtual selves and how do they spark new insights?

Based on the learning experience of our first set of performances, the project will move to the creation of a public installation in which ordinary people will experience their own *DigitalBeing*. As a fully interactive and participatory work, the *DigitalBeing* will make an artist of everyone by default, as they will effortlessly generate their own *DigitalBeing*. By bringing this, their "architecture of being" into existence, the *DigitalBeing* will challenge people's perceptions about themselves and their unfolding condition. Interpretations ranging from the erotic to the spiritual will fill the reading and participatory space of the installation. A digital recording of a participant's fleeting digital signature would be saved to a computer CD or DVD for later playback, thus maintaining the possibility for new interpretations.

8.8 Conclusion

In this paper, we have discussed a new ambient intelligent environment that expresses a dancer's arousal state through manipulation of sound/music and stage lighting as well as color of visual imagery projected around the dancers. The contribution of the paper is in the integration of an ambient intelligent system to the dance environment. The paper proposed an architecture composed of several intelligent systems. First, a sensor analysis system analyzes physiological sensor data as well as identifies lights on the stage that affect the dancer (at any given moment in time) given pressure sensor readings. Second, an intelligent lighting system initiates stylistic expressive manipulation of on-stage lighting over time reflecting the dancer's arousal state. An intelligent 2D visual imagery system that manipulates abstract colors to reflect dancer's state and being on projected imagery. Last, an intelligent sound/music system adapts the music based on the dancer's arousal state. We have discussed a prototype partially implementing the sensor analysis system and the intelligent lighting system, which was virtually represented.

The goal of the described architecture is to enable different modes of expression through a dance space, and provide a method that imprints a signature of the dancers' self in the physical dance space. In creating this signature, we seek to allow people to experience their own *DigitalBeing* and bring performance art to the people, while also offering to performance artists a creative tool to extend the grammar of the traditional theater dance. In future work, we aim to continue development of the architecture described and then evaluate its aesthetic utility within different dance forms.

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