

# Projecting Tension in Virtual Environments through lighting

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## ABSTRACT

Interactive synthetic environments are currently used in a wide variety of applications, including video games, exposure therapy, education, and training. Their success in such domains relies on their immersive and engagement qualities. Film makers and theatre directors use many techniques to project tension in the hope of affecting audiences' affective states. These techniques include narrative, sound effects, camera movements, and lighting. This paper focuses on temporal variation of lighting color and its use in evoking tension within interactive virtual worlds. Many game titles adopt some cinematic lighting effects to evoke certain moods, particularly saturated red colored lighting, flickering lights, and very dark lighting. Such effects may result in user frustration due to the lack of balance between the desire to project tension and the desire to use lighting for other goals, such as visibility and depth projection. In addition, many of the lighting effects used in game titles are very obvious and obtrusive. In this paper, the author will identify several lighting color patterns, both obtrusive and subtle, based on a qualitative study of several movies and lighting design theories. In addition to identifying these patterns, the author also presents a system that dynamically modulates the lighting within an interactive environment to project the desired tension while balancing other lighting goals, such as establishing visibility, projecting depth, and providing motivation for lighting direction. This work extends the author's previous work on the Expressive Lighting Engine [1-3]. Results of incorporating this system within a game will be discussed.

## Categories and Subject Descriptors

H.5. [Information Systems]: Information Interfaces and Presentation (e.g., HCI).

## General Terms

Design and Experimentation.

## Keywords

Visual perception, games, tension, emotions, arousal.

## 1. INTRODUCTION

Elaborate interactive virtual environments are becoming increasingly important for their utility in training, education, and entertainment. Advances in computer graphics, particularly in real-time rendering, have increased the complexity and fidelity of these environments. The need for advances in computer graphics is now superseded with the need for techniques to increase the engagement value and aesthetic appeal of such environments. Filmmakers and theatre directors have used many techniques to project tension in the hope of affecting audiences' affective states. These techniques include sound effects, camera movements (in case of film), and lighting effects. In this paper, the author investigates the use of lighting color and its application within interactive virtual worlds.

Currently, designers of interactive virtual worlds manually set the lighting throughout the game environment. In combination with this static lighting, some designers use dynamic lights to illuminate characters and objects or to light the environment through lamps, flashlights, and lanterns. The use of static lighting is inflexible, because it does not allow the lighting to adapt to the variations in the narrative context and the physical configuration caused by the interaction. While dynamic lights may adapt to some of these variations, the approach of using static and dynamic lights often results in environments that are imbalanced in terms of their lighting color compositions and luminance.

In terms of lighting for tension, several game titles, recently released, have shown the utility of some cinematic lighting effects for projecting excitement and fear. Examples include flickering lights interjected at specific moments in the game (e.g., *Doom 3*), darkly lit environments (*The Suffering*), or the use of saturated red colored lighting (*F.E.A.R.: First Encounter Assault Recon*, *Doom 3*). While the use of lighting in these examples was effective in projecting tension, it suffered from several problems. First, the use of these effects can sometimes cause user frustration; this is due to the lack of balance between the desire to project tension and the desire to use lighting for other goals, such as to establish visibility and project depth. Second, the lighting plan does not incorporate the change of lighting over time; to the author's knowledge, the effects are mostly triggered as a local event. Third, these patterns are often chosen because they are obvious, which also makes them obtrusive.

Besides the obvious flicker of lights and lightening clichés, cinematographers, dramateurs, and directors use several stylistic subtle temporal patterns that vary color features, such as contrast and affinity of color in terms of its warmth or coolness, saturation, and brightness, over time to project an increase or a decrease in tension [4-6]. Even though there are several examples of these patterns documented in lighting design theory, the documented cases are not comprehensive and are hard to represent computationally. The search for these patterns requires some research and understanding of lighting design techniques, the parameters involved, and their psychological effects. It should be noted that subtle lighting shifts and compositions are also very hard to notice for an untrained eye. In this paper, the author discusses a qualitative analysis of several movies presenting a list of stylistic temporal lighting color patterns that can be represented algorithmically. This analysis was conducted by a trained lighting designer, and thus accounting for lighting design elements that are often unnoticed by untrained eyes.

In addition to formulating lighting patterns, the author also discusses a system that extends ELE [1-3] (Expressive Lighting Engine, a system previously developed by the author) by algorithmically representing these patterns and dynamically manipulating the lighting in real-time to project the desired tension. The author hypothesizes that such an addition will lead to a more immersive and aesthetically pleasing interactive environment. To validate this claim, preliminary results of some informal self-reports will be presented. These reports were collected from participants who played two first person shooter games, one with the dynamic lighting system discussed in this paper and the other with static lighting.

This paper presents a set of contributions:

- a formulation for temporal cinematic lighting patterns describing the patterns, their use, and effect on the user's affective state.
- a dynamic system that
  - manipulates lighting in real-time projecting the desired tension by unobtrusively varying the lighting composition based on the study of cinematic patterns described in previous bullet.
  - establishes a well-balanced lighting design that attempts to satisfy several important lighting design goals, including evoking moods/tension as well as establishing visibility and maintaining realistic direction for lighting.

## 2. Current Techniques in Games

Several game titles adopt a static manual technique for lighting a game environment, whereby a designer, knowing the level of tension he needs to elicit, manually places lights and adjust their colors in the environment. An example game that uses such an approach is *Devil May Cry I*. In this game, the dramatic tension is broken into discrete segments or missions that are materialized when an appropriate level is loaded. In some cases, the difference between levels is only in texture or lighting colors; for example, the last level of *Devil May Cry I* is colored in a distinct saturated red color, signifying the climax.

While the technique works to supply the necessary tension through the game, it suffers several problems. From a design perspective, it is very tedious to redesign and relight each level. Additionally, the technique requires the designer to break the

continuous flow of tension and manually adjust the textures or lighting to accommodate the increase and decrease in tension. Furthermore, such an approach results in a static design, which limits lighting movements or variations within a level.

The recent inclusion of dynamic lights allowed game developers to investigate the inclusion of dynamic lighting effects, e.g. explosions and lightening. Horror films use many lighting patterns to evoke fear and shock, e.g. light flickering at specific situations in a movie to create anticipation and fear, or increasing darkness or contrast in specific parts of a movie for the same purpose. Examples of these patterns can be seen in several games, such as *F.E.A.R.: First Encounter Assault Recon*, *Silent Hill*, and *Doom3*. An example pattern used extensively in *Doom 3* is the sudden light flicker and the increase in saturated warm colors in certain areas in the level. These changes parallel the techniques used in Horror movies and tend to use dynamic lights mainly to evoke fear.

While this method creates a more dynamic approach to the use of lighting, it still suffers from many problems. These effects are scripted and thus need to be planned and the level need to be well designed for such dynamic change of lighting. For example, designers are required to plan texture lighting, texture colors, and the static lighting used, such that they would be in accordance with the desired shifts in color. Additionally, these changes are often computed with little consideration to the game play or other lighting design goals, which results in frustrating and badly lit environments. While it is always the artist's choice to sacrifice one goal for the other, oftentimes a balance can be achieved by simply balancing the lighting in the environment. This is difficult to achieve with a combined static and dynamic lighting approach.

In this paper, the author discusses a system that addresses these problems. The system uses dynamic lighting rather than a combination of static and dynamic, which provides better flexibility. The system presents a well-balanced lighting by adapting the lighting dynamically to produce desired tension as well as balance other lighting design goals. In addition, the system uses a set of cinematic lighting design patterns identified through a study of several movies within *Horror*, *Drama*, and *Sci-Fi* genres. This study was made to identify subtle but effective cinematic color patterns that can influence tension or arousal. The rest of the paper focuses on discussing these contributions.

## 3. FILM PATTERNS

As outlined in many film books, movies use several color and lighting techniques to create a desired effect based on the director's style [4-11]. In this section, several color patterns will be discussed. These patterns were formulated based on a qualitative study of over thirty movies, including *The Cook*, *The Thief*, *His Wife and Her Lover*, *Equilibrium*, *Shakespeare in Love*, *Citizen Kane*, and *The Matrix*. According to this 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 used 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 1. This kind of composition is used in many movies to project an increased tension. Perhaps the most well known examples of movies that use this kind of effect are film noir movies (shown in figure 2), e.g. *Citizen Kane* and *This Gun For Hire*.

Another form of contrast used in movies is the contrast between warm and cool colors [4]. An example shot appeared in several movies, including *The Shinning*, where the designer used a high warm/cool color contrast composition; 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 within a movie, such as turning points. Lower contrast compositions often precede these heightened shots, thus developing another form of contrast, contrast between shots.



**Figure 1.** Chiaroscuro Technique used in *Sacred love versus profane love* Painting



**Figure 2.** Film Noir uses contrasts and shadows

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 [4-11]. 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.

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

project dramatic intensity depends on the sequence and temporal ordering of the effects discussed above. For this purpose, patterns are defined in terms of techniques spanning several shots.

The first technique to 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. 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 a red color, the eye will try to compensate the red with cyan to achieve white color. With time, this correction process causes eye fatigue, which in turn affects the participant's stress level, thus affecting the projected tension level.

Based on this observation the following pattern is identified:

**Pattern I:** Subjecting audience to affinity of high saturated colors (where high saturation ranges from 70% to 100%) for some time increases projected tension

In contrast to the use of affinity, several movies use contrast between shots to evoke arousal [4, 12]. For instance, filmmakers use warm colors in one shot then cool 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, the following patterns are identified:

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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 projected tension

**Pattern 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

**Pattern 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 projected tension

**Pattern 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 projected tension

Although the author does not present conclusive proof of the effectiveness of these patterns in projecting increased or decreased arousal, it is assumed that these patterns are effective based on their use in films. The effect of some of these patterns on self-reported affective state has been confirmed experimentally in [13, 14].

Lighting design theory [4-11] discusses several other techniques that designers use to balance these effects with other lighting design goals, such as projecting depth, establishing necessary visibility, and providing motivating lighting direction. While these techniques are not discussed here, it is important to note that a good lighting design is one that composes a good balance between all of these goals. In this paper, the author attempts to show that tension patterns can be used in a dynamic system that balances lighting design goals based on lighting design theory.

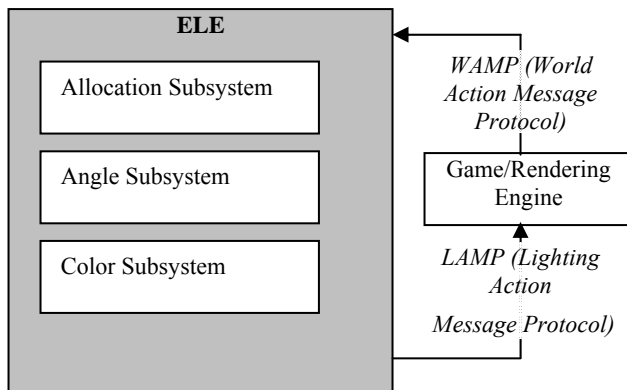


Figure 3. ELE's Architecture

#### 4. 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. These rules are represented mathematically in an optimization function. The use of optimization is important to balance conflicting lighting-design goals. While adapting the lighting to the interaction, ELE also maintains visual continuity and style.

ELE as a black box is illustrated in figure 3. 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, 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

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

- Number of lights to be used.
- For each of these lights:
  - type of instrument (e.g., spot light or point light)
  - color in RGB color space
  - attenuation
  - position as a 3D point
  - orientation including the facing and up vectors
  - range
  - masking parameters
  - The Penumbra and Umbra angles, if spot lights are used.

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. These subsystems are briefly discussed below.

Using theatrical and cinematic lighting design theories, ELE uses stage layout or scene graph information as well as artistic stylistic constraints to devise 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:

$$p_{opt} = \arg \max_p (\lambda_v V(p) + \lambda_d D(p) + \lambda_m M(p) + \lambda_{vc} VC(p)),$$

where  $p$  is light configuration,  $\lambda_v$  is the importance of visibility,  $\lambda_d$  is the importance of depth,  $\lambda_m$  is the importance of modeling, and  $\lambda_{vc}$  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  $p$ .

A greedy algorithm 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 influence of lighting 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:

$$\lambda_v(1-V(k, s)) + \lambda_- |k - k^-| + \lambda_m |k - m| + \lambda_l \min |k - l_i|,$$

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,  $\lambda_-$  is the cost of changing the key light angle over time (to enforce visual continuity),  $\lambda_m$  is the cost of deviation from the mood azimuth angle,  $m$  is the mood azimuth angle suggested by the artist,  $\lambda_l$  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  $\lambda_v$  is the cost of deviation from an orientation of light that establishes best visibility.

Based on Millerson's [15] documented rules the author formulated the following equation to evaluate the visibility and modeling of a given key light azimuth angle:

$$V(k, s) = \sin(k) \cos(s).$$

ELE uses rules based on Millerson's [15] guidelines to select fill and backlight azimuth angles depending on the value of the key light angle. According to Millerson's guidelines [15], fill light azimuth and elevation angles are calculated to be the mirror image of the key light angle. The author defines backlight azimuth angle as:

$$b = (k + \pi) \bmod 2\pi.$$

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 adhering to desired hue, saturation, and

lightness, and maintaining visual continuity. The cost function is defined as follows:

$$\lambda_d (D(c') - d)^2 + \lambda_c (\text{contrast}_\phi(c') - \delta)^2 + v(x) + \sum_{i \in \{f, n, b\}} P(c'_i, c_i^{t-1}),$$

$$\lambda_{s_i} (S(c'_i) - s_i)^2 + \lambda_{h_i} (H(c'_i) - h_i)^2 +$$

$$\text{where } p(c'_i, c_i^{t-1}) = \lambda_{l_i} (L(c'_i) - l_i)^2 + \lambda_{w_i} (W(c'_i) - w_i)^2 + \lambda_{ch} E(c'_i, c_i^{t-1}),$$

where  $c'$  is a vector of light colors for focus  $f$ , non-focus  $n$ , and background  $b$ , and areas at frame  $t$ . Color  $c'_i$  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 CIEDE2000, a well-known formula for measuring color difference [16, 17] as follows:

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

where  $\Delta R = R_T f(\Delta C \Delta H)$  and  $\Delta L$ ,  $\Delta C$ , and  $\Delta H$  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:

$$D(c) = \sum_{b \in B} \sum_{n \in NB} E(c_b, c_n),$$

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 [18], the author used a multiple, linear regression method to formulate color warmth in RGB color space, as follows:

$$\text{warmth} \begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{bmatrix} 0.008 \\ 0.0006 \\ -0.0105 \end{bmatrix}^T \begin{bmatrix} R \\ G \\ B \end{bmatrix} - 0.422.$$

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  $v(x) \rightarrow \infty$  as  $x$  approaches the boundary defined by the feasibility region. ELE uses the following formula for  $v(x)$ :

$$\varepsilon \sum_j^p \log(-g_j(x)).$$

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.

## 5. TEMPORAL DYNAMIC EXPRESSIVE LIGHTING ENGINE

The *Temporal Dynamic Expressive Lighting Engine* extends ELE by adding a state that keeps track of ticks (simulation time) as well as the history of lighting color compositions used in the past. This state is represented as a list of light colors for each area as well as contrast value and contrast type; color values are stored in terms of RGB and HSL as well as calculated warmth value. Based on this state information, the desired pattern given the patterns listed in section 3, and the desired tension level, the system calculates constraint values, including desired saturation level, desired warmth value, and desired contrast level. These values are then given to ELE to manipulate the current frame. Notice that ELE already balances these values with the required visibility, motivation, etc. Therefore, the resulting lighting setup created presents a balanced lighting design.

There are several advantages to using such a system. First, as discussed in section 3, the system embeds several patterns that are not used in the current dynamic lighting design methods in games. Second, it presents a system that establishes a well-balanced lighting design. Third, it allows designers to quickly compose the scene by just choosing the pattern and tweaking it, rather than re-designing the lighting in every level.

### 5.1 Prototype

Two prototypes were created for this system. The first prototype was developed to test the representation of patterns and their integration within ELE. For this purpose, the author created an interactive 3D environment using WildTangent, a publicly available web-based game engine; the environment is shown in figure 4. The task of the user was to navigate through the environment. The lighting conditions were varied as a function of time. The figure shows three screenshots taken at various times during the interaction. The lighting system was configured to use pattern IX, where brightness contrast subjected was decreased as a function of time (where brightness contrast is measured in terms of difference between bright and dark spots in an image). As the figure shows, visibility was well balanced with the contrast effect, as contrast increases or decreases in time.



Figure 4. Linearly increasing brightness contrast (where center of room is the focus)

For the second prototype, the temporal dynamic expressive lighting engine was integrated with the Unreal Tournament Engine [19]. An interface was added to enable developers to select the desired patterns of lighting variation. In addition, designers were also able to integrate their own tension formula and link it to these patterns. For example, they can define tension as the rise and fall of health within a first person shooter game. In this case, the temporal dynamic expressive lighting engine will manipulate the lighting in the room to project rise and fall of health as a symbol of tension. It should be noted that designers can use this tool to induce any of the patterns discussed in section 3. Thus, they can project the same lighting effects, such as the use of saturated warm colored lights, etc., as discussed in section 2. They can also use it to create a contrast effect such as high contrast (e.g., leftmost screenshot in figure 4) and sustain it over time.

### 5.2 Implemented in a Game

Using this implementation within Unreal, a first person shooter mod was developed. The lighting compositions varied within the level composed. For example, in the beginning a decrease of brightness contrast was established through the opening scene, shown in figure 5. At the end, a warm/cool color contrast as well as brightness contrast was used, as shown in figure 6.



Figure 5. Varying Brightness Contrast



Figure 6. Warm/Cool Color Contrast

During game play, the author increased or decreased tension based on danger. A danger value was defined as a function of health and number of enemies within the environment. The author used a combination of patterns I and III, where increase in tension was projected as an increase in warmth and saturation of surrounding lights. Thus, if the user is confronted with many monsters and his health is dropping over time, the warmth and saturation of color will increase over time showing an increase in tension. While if the player is killing monsters and danger level is



diminishing, warmth and saturation will decrease through time. Screenshots from the game are depicted in figure 7. A video of the demo can be found at URL: <http://faculty.ist.psu.edu/SeifEl-Nasr/ELEUnreal.html>.

It is hard to demo lighting, especially subtle lighting patterns. Therefore, for the purpose of the demo, the authors chose to use this particular pattern of red saturated colored lights, which was used in several games before. However, it should also be noted that there are several differences between the system and the methods used in current games. First, notice during the video that lighting colors are balanced with lighting colors on characters to emphasize visibility. This presents a well-balanced lighting design that takes game play into consideration. Second, the lighting does not stay constant at any one saturation or color; it changes in time as a function of danger.

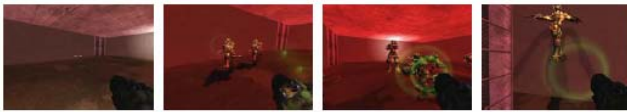


Figure 7. Linearly increasing Saturation

### 5.3 First Impression

An interactive demo of this system was presented within the *Interactivity* venue of *Computer Human Interaction Conference 2005* [19]. Several people played the demo after the author explained the premise of the game. All participants who played the game with the lighting system were also invited to play the game without the lighting system (i.e. using a static lighting design); this is important to clearly identify the difference in the experience.

Through observation and interaction with the participants, many interesting observations were made. Participants were excited about the system and voluntarily came to discuss their experience with the author after their play session. An interesting result was that many non-first person shooter players loved the game and the effect of the lighting. Some commented that it was beautiful and aesthetically pleasing to play with the lighting changes than with just static lighting. Some commented that they saw lighting as a method for portraying game information, which was unique in their experience.

Several first person shooter gamers played the two versions of the game. Some commented that the lighting gave them too much information and that impeded their game play, i.e. made the game too easy. Several others noted some disturbance by the lighting. One explanation was that many first person shooter players try to emotionally detach themselves from the game, but the lighting effects subconsciously attempt to draw the players in by manipulating the projected tension. In addition, some of them commented that this effect made them feel as if they are not in control. Perhaps this result confirms the success of the patterns in projecting tension, but alludes to the fact that the use of these patterns may need more study for different game genre.

## 6. CONCLUSION

The paper presents several contributions. First, the paper presents a quantitative representation of temporal cinematic color and lighting patterns. Second, the paper presents an automatic dynamic lighting system that includes a representation of these patterns and accounts for time and the influence of color on tension as well as provides a balance between tension and other lighting design goals. Third, the paper presents some anecdotal results that validate the use of these patterns in projecting tension within interactive environments. Even though the paper does not present conclusive experimental results that show the utility of the lighting patterns discussed on the participant's arousal state, it aims to lay a starting block in the development of a method for replicating cinematic techniques within interactive environments while taking into account the temporal nature of these techniques. This is particularly important because interactive environments are dynamic environments where lighting design elements, such as time, physical configuration, and narrative context change over time, thus, necessitating a dynamic adaptive technique as the one discussed in this paper. One of the limitations of the presented system is the omission of surface properties, such as textures, from the lighting calculation. The author aims to address this limitation in future work.

## 7. Acknowledgements

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