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Preface

Dear participants

I would like to welcome you, here at the Mediadesign Hochschule Düsseldorf, to the 10th edition of the Annual European Conference on Simulation and AI in Games on behalf of all the people and institutions that made this conference possible.

Even though the present economic climate has had an adverse effect on participation, this year's event still has managed to attract some 13 high quality papers from 10 different countries spanning 3 continents, out of 20 papers submitted.

Further to the selected scientific presentations, EUROSIS and I are grateful to Jan-Anton Derer, for giving this year's keynote speech entitled: "Challenges of AI in Games".

I wish to thank all those, who have contributed their time and effort in organizing this meeting. This goes out to the International Program Committee members who took care of the reviewing process. They have done a great job in arranging a strong technical program, which covers a variety of speciality areas covering present day methodological simulation research.

Recognition for this conference must go also to Philippe Geril, the EUROSIS coordinator, who was the main force responsible for the organisation of the meeting.

Furthermore, I would like to thank UBISOFT, for accepting to have the conference participants visit their studios in Düsseldorf.

Finally, I would like to wish you a pleasant stay in Düsseldorf and a successful conference meeting

Professor Dr Linda Breitlauch
GAMEON'2009 General Conference Chair
Mediadesign Hochschule
University of Applied Sciences
Düsseldorf, Germany

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Barbaros Bostan
National University of Singapore
Games Lab, 21 Heng Mui Keng Terrace
Singapore, 119613
E-mail: idmbb@nus.edu.sg

Ugur Kaplancali
Yeditepe University
Kayisdagi Cad. 26 Agustos Yerlesimi
Istanbul / Turkey, 34755
E-mail: ugur.kaplancali@yeditepe.edu.tr

ABSTRACT

Player motivations are a popular research area in computer gaming. But beyond the identification of a limited set of motives, research so far has been neither concerned with how these motivational variables interact with each other, nor how they relate to individual player actions. This article, assuming that player motivations are the outcome of continuous player-environment interactions, applies the needs framework of Murray (1938) to a computer game and investigates the relations between each individual need and the driving game mechanics behind them. It is shown that the restrictions imposed by the game mechanics significantly reduce the number of player needs satisfied by a game, thereby trapping the player within the common motivational cycle of *Achievement*, *Aggression*, *Harmavoidance* and *Acquisition.*

This motivational study on gaming experience should facilitate the design of computer games that satisfy a broader range of player needs by providing ways to investigate the matching actions for each individual need while identifying the common patterns imposed by game mechanics. Analysis of player motivations on action level should also open up new frontiers in the player profiling process in interactive gaming experiences that should ideally appeal to many types of players. This discussion is framed in terms of the user-environment relations of a recently released popular computer role-playing game (RPG). It is stressed that the gaming experience provided by this genre is analogous to real life and thus has the potential to satisfy a broader range of player motivations.

Keywords: Player Motivations, Player Psychology, Human Factors, Gameplay Experience

PLAYER MOTIVATIONS

Maximizing player enjoyment is one of the primary concerns of game designers, but classical theories about the individuals' motivation to use entertainment products for enjoyment are not applicable to computer gaming. This is because players are not passive witnesses of the virtual world but are active participants in an imaginary setting where interaction and immersion play a crucial role. Maximizing enjoyment in these interactive virtual environments is possible by analyzing player psychology which is affected by his/her personal factors such as needs, motives and goals, as also by situational factors such as opportunities and possible incentives provided by the environment.

Most researchers analyzing the psychology of the player are concerned with the educational value of computer games (Provenzo 1991; Stewart 1997; Appleman & Goldsworthy 1999; Prensky 2001, 2002; Squire 2003; Squire and Jenkins 2003; Gee 2003, 2005; Egenfeldt-Nielsen 2007; Shelton and Wiley 2007) or the negative effects of gaming and violence in video games (Anderson and Ford 1986; Cooper and Mackie 1986; Anderson and Bushman 2001; Sherry, 2001; Anderson 2004; Gentile et al. 2004; Bartholow et al. 2006; Weber et al. 2006; Anderson et al. 2007). Besides the intrinsic motivations taxonomy of Malone and Lepper (1987) and the flow framework of Csikszentmihalyi (1990) have already been applied to computer gaming (Sweetser and Wyeth 2005; Kellar et al. 2005), research on player motivations include a variety of other approaches too: using TAM (technology acceptance model) in conjunction with flow framework (Hsu and Lu 2004); analyzing motivations of MMORPG players in the context of Bartle's (2004) playstyles (Yee 2006); applying SDT (self-determination theory) to computer gaming (Ryan et al. 2006); applying MRL (motivated reinforcement learning) to model motivations of non-player characters (Merrick 2007); and analyzing the relationship between MMORPG game structures such as character design, narrative environment, etc. and intrinsic motivations (Dickey 2007).

However there are only a handful of studies that analyze the relationship between individual motivations and the gaming experience. Applying Maslow's hierarchy of needs to computer gaming, Joyner and TerKeurst (2003) questioned why people play computer games but they were not concerned with the in-game motivations of players. De Sevin and Thalmann (2005) focus on the action selection process and use motivational variables such as hunger, thirst, resting, sleeping, cooking, cleaning, etc., some of which are physiological in nature, and some not motivations but daily activities. Assuming that human motivation is triggered by the psychological needs of the organism, this article analyzes in-game needs of game players in relation to their actions within the virtual environment.

Psychological Needs

A need refers to a potentiality or readiness to respond in a certain way under given conditions and each need is characterized by a certain effect or the occurrence of a certain trend (Murray, 1938). The most popular study on human needs is conducted by Maslow (1943; 1968) who identifies a hierarchy of needs in man ranging from the lower-order physiological drives to higher-order psychological motivations. McDougall (1908) made the pioneering attempt to define the whole human behavior in terms of innate psychophysical dispositions (instincts), but it was Murray (1938) who formalized the study of needs. His three-year study at the Harvard Psychological Clinic was conducted by 28 psychologists of various schools, among whom were three physicians and five psychoanalysts. The psychogenic needs of Murray, which are psychological in nature, are not static entities but the result of both internal and external forces, and are concerned with mental and emotional states of a person. 27 psychogenic needs of this framework have already been analyzed by (Bostan 2009) in relation to the gaming situations of a RPG. This article attempts to take this study one step further by analyzing the common fusions of individual needs and by defining the driving game mechanics behind them.

Although similar classifications of needs (Mayer, 2007; Carver and Scheier, 2000) exist, this study focuses on the six categories of needs defined by (Bostan 2009). In summary, there are four materialistic needs representing Acquisitive, Constructive, Orderly, Retentive attitude, six power needs representing Aggressive, Blamavoidant, Counteractive, Defendant, Deferent, Dominative attitude, five affiliation needs representing Abasive, Affiliative, Nurturant, Rejective, Succorant attitude, six achievement needs representing Achievant, Autonomous, Fearful, Infavoidant, Self-forwarding, Exhibitionistic attitude, three information needs representing Inquiring, Informing, Intellectual attitude, and three sensual needs representing Playful, Sentient, Erotic attitude. Discussing the specifics of each variable is beyond the scope of this article, but those interested in them can consult (Bostan 2009) who analyzed these needs with matching gaming situations.

Table 1: Psychogenic Needs of Murray (1938)

Materialistic Needs *nAcq:* Acquisition *nCons:* Construction *nOrd:* Order *nRet:* Retention	**Power Needs** *nAgg:* Aggression *nBlam:* Blamavoidance *nCnt:* Counteraction *nDfd:* Defendance *nDef:* Deference *nDom:* Dominance
Affiliation Needs *nAba:* Abasement *nAff:* Affiliation *nNur:* Nurturance *nRej:* Rejection *nSuc:* Succorance	**Achievement Needs** *nAch:* Achievement *nAuto:* Autonomy *nHarm:* Harmavoidance *nInf:*Infavoidance *nRec:* Recognition *nExh:* Exhibition
Information Needs *nCog:* Cognizance *nExp:* Exposition *nUnd:* Understanding	**Sensual Needs** *nPlay:* Play *nSen:* Sentience *nSex:* Sex

Murray (1938) defined each need with appropriate desires and effects, matching feelings, emotions, personality traits, and common relationships with other needs such as fusions, conflicts, and subsidiations. A single action pattern may satisfy two or more needs (fusions), one or more needs may be activated in the service of another need (subsidiation of needs) and the needs may conflict with each other. These interrelations, which depend heavily on the game mechanics and how they are used, may exhibit very complex combinations in the game world. For example, Player A may wear the same guild badge as does Player B, because he/she does not wish to make a bad impression (Infavoidance) and instead wishes to win B's friendship (Affiliation), so that he/she will learn the secret location (Cognizance) of the guild treasury and loot it for acquiring the famous dragonlance (Acquisition) and using it to attack (Aggression) the legendary red dragon living in the mountains and thus level up (Achievement) (nInf, nAff, nCog, nAcq, nAgg, nAch fusion). To identify the common patterns behind these complex interrelations, the next section is devoted to analyze Murray's needs in relation to the game mechanics of an RPG.

A DECOMPOSITION OF GAME MECHANICS

The needs framework of Murray (1938) can theoretically be applied to computer game of any genre, but the range of needs satisfied by a computer game is usually limited by its content and rules of play. For example, information needs are prominent in adventure games where players focus on exploration and puzzle-solving within a narrative framework, whereas social simulation games, such as *The Sims,* are built on the theme of affiliation. In this regard, role playing games are perfect candidates for analyzing the motivational aspects of a gaming experience, because they satisfy a wider range of psychological needs.

The RPG selected for this study is *Fallout 3* which was developed and released by Bethesda Softworks in October 2008. Besides the many awards it won, the game was adjudged the best game of 2008 at the annual Game Developers Conference (GDC 09). *Fallout 3* is set in the backdrop of post-apocalyptic Washington D.C., 200 years after the Great War in 2077, where nuclear bombardment ravaged the earth's surface for two hours. The game depicts a post-nuclear world in great detail with dreary and desperate overtones. Besides the features common to the games of this genre, such as being an interactive and social world populated by autonomous virtual characters, the game also has an open-ended structure that allows the players to freely roam in a virtual environment with high visual and behavioral realism.

Figure 1: Washington Monument as seen from Capital Mall.

Discussing different definitions of game mechanics is not the primary objective of this article. An elaborate discussion of previous definitions of game mechanics has already been presented by Sicart (2008). What interests this article is something more similar to the core game mechanic as defined by Salen and Zimmerman (2004). A core game mechanic, which represents patterns of behavior or building blocks of player interactivity, may be a single action or a set of interrelated actions which form the essential play activity that is repeated throughout a game. This article aims at analyzing these single actions or sets of interrelated actions to delineate the motivations behind each of them. Motivational variables are represented with polarity, such as +nAgg which motivates aggressive behavior (situations with positive incentive for aggression) or –nAgg which motivates the avoidance of aggressive behavior (situations with negative incentive for aggression).

Basic Game Mechanics of Fallout 3

Every character in *Fallout 3* has seven primary statistics: Strength, Perception, Endurance, Charisma, Intelligence, Agility, and Luck. Extracted from these are the derived statistics which define the basic game mechanics. Skills represent a variety of abilities, each governed by an attribute, which provide the player a means for interacting with the virtual world. Characters are also given perks (special abilities) which are extensions of the skills possessed by a player. Showing similar characteristics with AD&D table-top role playing games, character progression in Fallout 3 is governed by experience points (XP) earned by completing a quest, defeating a monster, learning a secret, convincing an NPC to help, solving a puzzle, etc.

It needs to be noted that game players are already familiar with the game mechanics of *Fallout 3*, because it is the sequel of three titles with the same name (*Fallout, Fallout 2 and Fallout Tactics: Brotherhood of Steel*) and also its game rules are similar to AD&D game rules frequently utilized in RPGs. Only a few derived statistics from the previous titles, such as armor class, healing rate, poison resistance, etc. have been deleted in *Fallout 3*, and a few minor changes made in skills, such as moving parts of throwing skill to explosives skill, merging doctor and first aid skills with the medicine skill, splitting traps skill into explosives and repair skills, etc. In summary, the common forms of player interaction that are repeated throughout the game remained almost the same.

Analysis of Fallout 3: Derived Statistics & Skills

Before analyzing the game mechanics of *Fallout 3* from a needs perspective, it is important to note that the unique nature of *Achievement* requires special attention. According to Murray, nAch is the dominant psychogenic need that fuses readily and naturally with every other need. Similarly, nAch fuses with every other need in a computer game and every single action of the player contributes to his/her achievement. This contribution, which is quantifiable in terms of experience points, is more noticeable in RPGs. Every skill used, every item purchased or found, every dialogue option selected and every region explored eventually assists the user in gaining more experience points or achieving a new level in the game. Thus, nAch will not be specified in the motivational analysis of the game mechanics, unless it is the only dominant need of a derived statistic or skill. Given below are derived statistics and skills of *Fallout 3*, their descriptions and relevant motivational variables.

Table 2: Derived statistics and motivational relations.

Statistic	**Description**	**Needs Satisfied**
Action Points	Number of things a player can do during Vault-Tec Assisted Targeting System, or V.A.T.S. See V.A.T.S. below for further explanation	+ nAgg, + nHarm
Carry Weight	Maximum amount of weight a character can carry. Carrying more items means retaining more possessions.	+ nAcq, + nRet
Critical Chance	Chance to cause extra damage in combat. Critical hits provide a means for quick elimination of enemies and receiving less damage in combat.	+ nAgg, + nHarm
Damage Resistance	Reduces damage taken from attacks.	+ nHarm
Health	Hit points or the game mechanic used to measure the health of the player.	+ nHarm
Radiation Resistance	Reduces damage taken from radiation.	+ nHarm
Perk Rate	How often player is given a perk.	+ nAch

V.A.T.S: Vault-Tec Assisted Targeting System, or V.A.T.S. is an action queuing system that enables the players to shoot specific body parts in turn-based combat. Targeting in V.A.T.S enables the player to cripple specific body parts of enemies, thus rendering them less effective in combat in various ways. For example, because crippling an enemy's head reduces his/her perception, the player can run away or hide. V.A.T.S. increases the precision of attacks and causes more damage (sometimes dismembering enemies) than in real-time combat. The alternative for V.A.T.S. is real-time combat which usually takes more time to eliminate enemies, thus causing to receive more damage in the process.

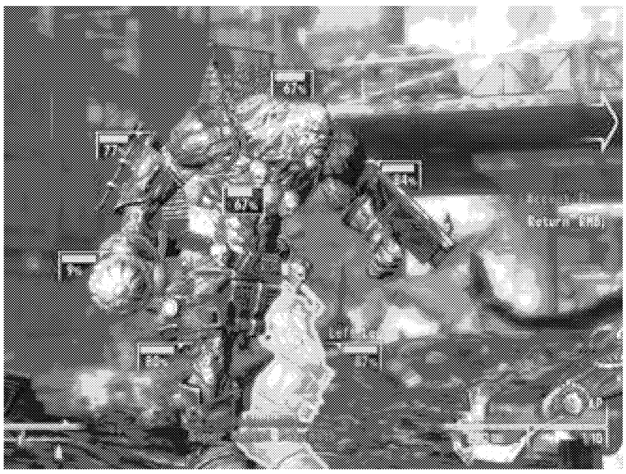

Figure 2: V.A.T.S. screen initiated on a Behemoth.

The most common fusions arising from the analysis are between +nAcq and +nRet (both of which are associated with inanimate objects), and between nAgg and nHarm (which exhibit a more complex pattern). The fusion between +nAgg and –nHarm indicates a more aggressive behavior, because the player is more captivated by the thrill of eliminating enemies than being concerned with the injuries or damage he/she may receive in the process. Using melee weapons is an example of this fusion. The player is aware that he/she has to engage in close combat which, depending on the enemy to be faced, usually results in receiving more damage. Of course, there are other mechanics that compensate for this loss of health such as wearing damage-resistant power armors or using proper medication, but the action itself is an aggressive one. The fusion of +nAgg and +nHarm refers to a more conservative behavior and tactical planning. Placing explosives in strategic positions is an aggressive act, but it is surely a safer way of eliminating certain enemies such as Mirelurk Hunters which move faster than the player and inflict tremendous damage when engaged in close combat. As player skills serve different needs, critical choices in skill usage are represented with AND/OR structures in the following table.

Table 3: Player skills of *Fallout 3* and motivational relations.

Skill	**Description**	**Needs Satisfied**
Barter	Decreases the value of objects when buying, increases their value when selling.	+ nAcq
Big Guns	The ability to use bigger weapons such as flamer, gatling laser, minigun, missile launcher, etc.	+ nAgg
Energy Weapons	The ability to use energy-based weapons such as laser pistol, plasma rifle, pulse pistol, etc.	+ nAgg
Explosives	The ability to set or disarm explosives, also increases damage of explosives such as mines, grenades, etc.	+ nAgg AND/OR + nHarm
Lockpick	The ability to open doors or safes without the proper key. Also promotes gaining access to places, avoiding heavily enemy crowded areas.	+ nAcq AND/OR + nHarm
Medicine	Increases the health earned from medical items such as stimpaks, radaways, etc.	+ nHarm
Melee Weapons	The ability to combat with melee weapons such as a sword, knife, etc. Close combat results in receiving more damage.	+ nAgg, – nHarm
Repair	The fixing of broken equipment, machinery and electronics. Repair is also used to disarm traps (non-explosive traps like tripwires) or to make new items. The user also profits from repairing items since he/she is capable of carrying more valuable equipment for the same weight.	+ nRet, + n Acq AND/OR + nHarm AND/OR + nCons
Science	The ability to hack computers terminals and electronic equipment. Terminals in the game allow the user: (1) to turn off turrets (2) to open safes (3) to access information (4) to control robots	+ nCog AND/OR + nHarm AND/OR + nAcq
Small Guns	The ability to use pistols, shotguns, assault rifles and rifles.	+ nAgg
Sneak	The ability to move silently. Also enables the player to steal items from others. See below for further explanation.	+ nHarm AND/OR + nAgg AND/OR + nAcq
Speech	The ability to persuade or influence others. See below for further explanation	See below
Unarmed	The ability to combat with hands and feet. Close combat results in receiving more damage.	+nAgg, – nHarm

Sneak: Sneaking can be used as a defensive strategy to avoid combat or to inflict more damage on enemies in the form of sneak-critical attacks. It is even possible to eliminate enemies with one-hit sneak critical, without receiving any damage in combat. Stealing ammunition also disables the NPCs from firing their weapons and thus protects the player from damage. And, reverse pick-pocketing is a special form of acquiring an item. If the player wishes to steal some equipment that an NPC wears (which is of course not suitable for stealing), then he/she can reverse pick-pocket and place a better item in the NPC's inventory. The NPC will eventually equip the better item, and neglect the item player wants, thus rendering it vulnerable to be pick-pocketed.

Figure 3: Player character sneaking behind some bushes.

Speech: The speech skill is used to communicate effectively in persuading and influencing the NPCs. Although it sounds like an *Affiliation* oriented skill, its primary concern is not to forge friendships or associations, but to affect others. To influence or direct the behavior of others by suggestion, seduction, persuasion, or command is an act of *Dominance,* but the underlying mechanisms behind this skill provide different forms of fusions between other needs which are imposed by game mechanics. To define the relationship between the speech skill and each individual need, relevant gaming situations are analyzed. Throughout the game, 87 gaming situations, where the speech skill plays a major role, have been experienced. Twenty-nine percent of these are used to convince an NPC to do something so as to avoid confrontation. This is how the player chooses to solve problems more peacefully by persuading or influencing people, instead of using brute force and getting harmed in the process. To cite an example, General Jingwei, who is the primary villain of *Operation Anchorage* (the first downloadable content pack of *Fallout 3*), can be persuaded to commit suicide. If the player fails to persuade, he/she has to fight with the General.

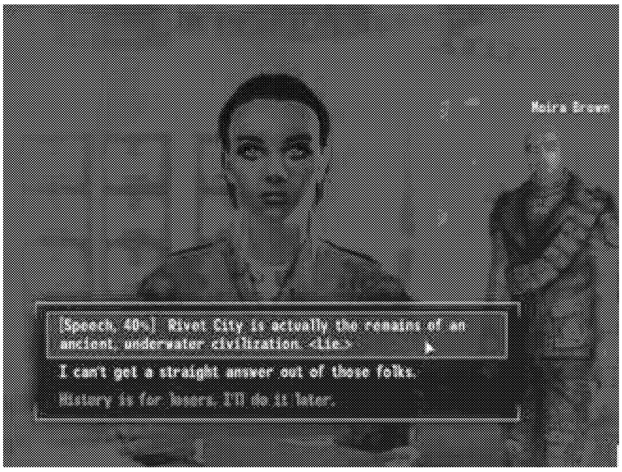

Figure 4: Speech skill used on an NPC.

Twenty-five percent of the gaming situations are used to convince an NPC to give something - personal gain or benefit – to the player. The most common form is to request for greater reward/more benefit for a quest or an item. Another 25% of the situations are used to convince an NPC to tell something, to gather information about something or someone and 8% to do something, solely for finishing a quest. From the remaining gaming situations, 5% are used for learning information and avoiding confrontation, 5% for acquiring an object from an NPC to avoid confrontation, and 3% for helping people with no additional reward. Gaming situations relevant to the speech skill show that there are some cautious choices in the game that offer a fusion between –nAgg and +nHarm. These choices are important indicators of a trend for non-aggressive behavior. Players can avoid confrontation and find a peaceful solution to a problem, which might otherwise require weapons to be drawn. Two other remarkable fusions are between +nDom and +nCog, and +nDom and +nAcq. These dominative or authorative choices are used either for information gathering or for object acquisition. Gathering information is vital for completing quests in the game but the dominative act of object acquisition usually comes in the form of ill-gotten gains.

Table 4: Gaming situations relevant to speech skill.

Percentage	**Description**	**Needs Satisfied**
%29	Avoiding confrontation	+ nHarm, – nAgg
%25	Acquiring something	+ nAcq, + nDom
%25	Gathering information	+ nCog, + nDom
%8	Finishing a quest	+ nAch
%5	Acquiring something & Avoiding confrontation	+ nAcq, + nHarm, - nAgg
%5	Gathering information & Avoiding confrontation	+ nCog, + nHarm, - nAgg
%3	Helping someone	+ nNur

The Importance of Choices in Analysing Player Actions

Although the game mechanics analyzed in this study are chosen from a role-playing game (RPG), it is also possible to analyze basic games using this motivational framework. For example, the *Pacman* game is primarily governed by the needs of *Harmavoidance* (running away from the ghosts), *Achievement* (getting to next level and increasing the game score), *Aggression* (eliminating ghosts by eating power pellets) and *Acquisition* (acquiring pills or other objects). Similarly, the four major game mechanics of a RPG are gaining experience, acquiring objects, avoiding harm and eliminating enemies. Thus, it is not surprising to see that the three dominant needs (besides nAch) of *Fallout 3* are nAgg, nHarm and nAcq. But the critical factor that determines the difference between action patterns of players is how they use the mechanics when they are given a choice. Micro choices are moment-to-moment choices of a player; the way these micro-choices fuse as a long-term strategy defines the macro level of a choice (Salen and Zimmerman 2004). As the system responds in some way to every player choice, the action-outcome unit of a choice defines the meaning that emerges in a game.

For instance, if a quest requires the player to kill an opponent when he/she has no other option, then the act of killing cannot be considered inclination towards aggressive behavior. It can be considered so only when the player has other options. For example, the sneak skill in *Fallout 3* has a variety of uses. The player usually notices the enemies before the enemies notice the player, and it is up to the player how he/she overcomes obstacles. Some alternatives are to ignore the enemy by sneaking from a safe distance, to directly attack the enemy with a weapon of choice or to sneak to a favorable position and eliminate the enemy quickly taking advantage of surprise and without receiving much damage in the process. It is these choices in a computer game that determine the play style of a player and indicate his/her trends in motivation. But the player's actions before and after the choice are also important determinants for understanding his/her motivations of the player. If the player is low in health and ammunition before the choice, it is understandable why he/she avoids a powerful group of monsters (nHarm inhibiting nAgg). And, one who loots every single enemy after the combat is not like the one who ignores the dead bodies and proceeds to his/her next quest destination (macro level of a choice).

CONCLUSION

Murray's framework is applicable to computer gaming, because it can match player motivations to different gaming situations. It is obvious that the relative importance of the needs may change from one game/genre to another, but the variables of this taxonomy could assist the analysis of gaming experiences within a motivational framework. Nevertheless, the framework needs some modifications, because some of the actions are specific to computer gaming (to disarm traps, to pick locks, to sneak attack, to pickpocket, etc.) which can not be found in the original study. Also, there is a need to redefine the fusions and conflicts, because what are proposed to be common fusions or conflicts may show different patterns when the player interacts with a virtual environment (such as the common +nAgg & +nHarm fusion). Although Murray neither defined the specifics of seven needs nor systematically used them in his study (nAcq, nBlam, nCog, nCons, nExp, nRec and nRet), the exploration of core game mechanics in this study indicate some common patterns among these needs (+nRet & +n Acq, +nAcq & +nDom, +nCog & +nDom).

It should be noted that the needs to be satisfied by the gaming situations are constrained by the imposed mechanics of the game and most of the needs in Murray's taxonomy (1938) are not fulfilled at all. On the other hand, tying all the gaming situations related to the needs of *Affiliation* and *Power* to one game skill (speech skill) may not be the wisest choice. Most of the research on the forms of interaction and communication between characters focuses on multi-player environments. However, if designers wish to satisfy a broader range of player needs, they should provide in single player computer games also richer verbal and non-verbal communication forms and dialogue options with meaningful choices. The identification of individual player needs and their corresponding actions should also aid research on dramatic characters in interactive storytelling experiences. In this regard, Laurel (1997) commented that dramatic characters are better suited to the roles of agents than full-blown simulated personalities and these characters can be represented by personality aspects which are appropriate to a particular set of actions and situations. Similarly, Manovich (2001) noted that narrative actions are more important than the narration itself.

This study should also aid researchers and game designers in identifying various user preferences and play styles, and thus provide a method for profiling gamers. But, the critical issue is what kind of choices are given to the player and how they are constrained by the game mechanics. Certain skills of *Fallout 3* (explosives, lockpick, repair, science, sneak) can be used for different purposes (represented with AND/OR structures); how the player chooses to use them might give an idea about different play styles. Also, certain needs such as Infavoidance, Blamavoidance, Defendance, etc., can be satisfied more easily if player choices are not black and white stereotypes and if they have a meaningful impact on the virtual world and its inhabitants (Bostan 2009). In terms of player profiling, even the popular playstyles of Bartle (2004) have never been empirically tested to validate that the four player types (Explorers, Achievers, Killers and Socializers) are independent of each other. In fact, it is even more difficult to discriminate between these playstyles in a single player RPG. For example, if the player is exploring the whole map of *Fallout 3*, he/she is assumed to be an Explorer but his/her motivation could be just to complete all the quests (nAch), to acquire all unique items (nAcq), to eliminate every single enemy (nAgg) or could be all of them. Thus, future studies should investigate if independent player profiles or playstyles can be defined with the variables of this taxonomy.

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Psychologically Verified Player Modelling

Giel van Lankveld, Sonny Schreurs, Pieter Spronck
Tilburg University

KEYWORDS

Player modelling, personality, trait theory, five factor model.

ABSTRACT

This research attempts to measure personality by monitoring behaviour in a virtual environment. A computer game was created to measure a trait of the Five Factor Model of personality: extraversion. Test-items were created to measure extraversion and its facets, as specified by Costa and McCrae [7]. For this purpose, 25 items were built into the virtual environment. In order to test if these measures actually measure extraversion and its facets, an experiment was conducted. In this experiment 24 participants completed our computer game and filled out an existing personality questionnaire, the NEO-PI-R [7]. Multiple Regression Analyses was used to test the correlations between the test items and the NEO-PI-R scores. Five of the items had a positive correlation with the NEO-PI-R extraversion-score, indicating that test-items in a virtual environment can actually be used to measure extraversion. We conclude that it is possible to measure personality traits, and consequently a valid psychological profile, through automatic observation of player behaviour in games.

INTRODUCTION

Personality profiling concerns the mapping of human characteristics to a model. Deciding what constitutes a good model has long been a matter of debate [18]. Over time the five factor model emerged as the best established and most validated model of personality [12]. Nowadays, the five factors of this model are generally considered to be the main structure of human personality [6]. Based on their research, Costa and McCrae [9] even suggest that the five factor model is the universal structure of personality.

The most widely accepted instrument for measuring the five factor model is the NEO-PI-R personality test [6], which is used in the present research. The factors of the five factor model are Extraversion, Neuroticism, Agreeableness, Conscientiousness and Openness to experience. The NEO-PI-R measures an individual's "characteristic and enduring emotional, interpersonal, experiential, attitudinal, and motivational styles" and is therefore suitable for measuring individual differences in various situations [11].

Personality theory has demonstrated its use in a variety of areas. It has shown that there is a consistent relationship between conscientiousness and academic success [22], that drinking motives are related to extraversion [25], and that low agreeableness combined with low conscientiousness predicts juvenile delinquency [19]. Personality profiling is also used in practice to profile offenders and aid law-enforcement agencies in understanding their motives [3].

Limitations in Personality Questionnaires

Current methods of personality profiling encompass written tests, verbal tests, and observational studies. These methods suffer from several drawbacks, which are discussed below.

Both written tests and verbal tests are based on the assumption that a respondents reports are truthful. Thus, they are vulnerable to inaccurate or untruthful self-reporting. It has been shown that respondents are unable to accurately report their own habits. Gross and Niman [17] point out that self report data have little correlation to actual behaviour frequencies.

Observational studies are considered to be more reliable and more objective than self reports [1]. However, these studies suffer from high cost and high effort in data collection. Gathering sufficient data through observational studies to form an adequate model of personality may take years of work and involves numerous observations on numerous subjects [10].

All explicit tests of personality are vulnerable to socially desirable behaviour. People tend to act more socially favourable when they feel they are being evaluated or judged, by presenting themselves in a more accepted fashion. An example of this is that people tend to act more conscientious than they really are [15].

Motivation

To alleviate the problems of the personality tests in use today, this research aims to create an implicit observational test that is administered by a virtual environment. The function of this test is to measure personality using automated observation without the need for human effort. In the past this was considered to be virtually impossible [10].

The goal of the present research is to model a subject's personality automatically based on their actions and choices in the game. The risk of using a game is that players can act unlike their 'real-life personality' and more like the role of the character that they play. However, we assume that, even if subjects are playing a role, there will still be characteristic behavioural patterns that belong to their personality.
Game environments have the advantage that they provide the opportunity to incorporate many types of personality tests. In a game information can be offered in implicit and explicit ways as well as in observational items and self-report fashions.

Problem Statement

This research investigates the possibilities of using virtual environments to profile personality. We investigate the correlations between behaviour in the game and personality test scores. The problem statement that guides the research is: *To what extent is it possible to build a psychological profile of a person by monitoring his actions in a virtual world?*
We attempt to solve this problem by comparing behaviour in a virtual environment to responses on the NEO-PI-R test. To the best of our knowledge, no previous research on this topic exists. In the present paper we limit our research to just one personality trait, namely extraversion.

Outline

This first section provided a short introduction to the field of psychological profiling and the reasons why we think a new way of testing would be a welcome addition to the currently available tests. The next section gives an overview of the theoretical framework of the history of the five factor model and its most important tests and practical uses. A further insight into the extraversion trait is also given. We then describe our experimental setup used for conducting the experiment, after which we present our results and derive conclusions and recommendations future research.

BACKGROUND

In this section we present a theoretical framework for our research, discussing the five factor model, the extraversion personality trait, and player modelling and profiling.

The Five Factor Model

Comparisons between people are commonly based on traits [18]. The earliest known personality descriptions were suggested by philosophers. They first explored personality through observation and reasoning. They tried to understand illness, emotional suffering, and behaviour [20]. Thinking about personality followed a logical rather than empirical line of thought.
In the 19th century psychiatry explored personality in an attempt to cure mental illness. Freud and Jung were among the first to examine properties of the mind in order to diagnose dysfunctional behaviour [16]. Freud's ideas were based on personal philosophies, while Jung required empirical evidence and fact to support his theories [24]. Jung's ideas are at the basis of modern psychology.
If a psychological theory is empirically validated and the model is standardised it can be used to compare individuals to groups of people. William Wundt started the empirical validations of personality by using experimentation. Wundt laid the basis for modern experimental research methodology, and investigated various domains of psychology including consciousness, perceptions, sensations and feelings [20]. These accomplishments lead directly to the domain of psychological profiling.
At the start of the 20th century personality theory was seen as a chaotic and unstructured field. Personality was being researched in different levels of abstraction and from different perspectives [19]. Each perspective contributed to the field but the diversity of personality scales measuring the different perspectives on personality made it impossible to compare and choose scales [18, 19]. In order to give structure to the field of personality research, a descriptive model was needed. A single taxonomy would allow for comparison and structure between scales and perspectives [19]. One taxonomy was found in which the entire field could be represented: *the five factor model of personality.*
The five factor model was based on the terms people use to describe each other's stable attributes. The model divides personality into five domains by which a description of someone's personality can be given. The model was designed by analysing the natural language terms people use to describe one another [19]. Thurstone [27] was the first to suggest a system of five domains. Several other researchers found evidence for a system of five factors. This marked the start of the five factor model [28].
The five factor model was independently confirmed in several studies but received near fatal criticism. Mischel [21] criticised the trait approach in general and disputed the reliability of five factor research up to that time. Costa and McCrae [11] also provided criticism but also provided a more reliable instrument as the solution to the criticisms: the NEO-PI-R.

The NEO-PI-R

Costa and McCrae developed the first robust tool for measuring the five factor model: the NEO-PI (which is an abbreviation for Neuroticism, Extraversion and Openness to experience Personality Inventory). The

NEO-PI was meant to replace earlier, suboptimal tests measuring the five factor model [11]. The earliest versions of the NEO-PI measure only three personality traits, in the following years two others were added.
The NEO-PI divides every trait into six facets. These facets provide a detailed specification of the contents of each domain [8]. The facets were designed to be supported by existing literature. They were meant to be similar in breadth and should represent "maximally distinct" aspects of each domain.
A more modern test, the NEO-PI-R (the 'R' standing for 'revised'), is now considered a reliable and valid test for personality. It contains 240 items measuring the five domains and their facets. It has been thoroughly tested [11], and is widely accepted as the standard model of personality structure The domains of the five factor model as labelled by Costa and McCrae and tested by the NEO-PI-R are: Extraversion, Neuroticism, Agreeableness, Conscientiousness and Openness to Experience.

Extraversion

In this research we focus on the trait of extraversion. This trait was first proposed by Jung, who described it as the inward or outward focus of libido. Introverts tend to turn their energy, focus and orientation towards themselves, while extraverts focus outside themselves. Costa and McCrae [7] describe people with high extraversion as sociable, meaning they prefer to be in the company of others and in social situations. They introduced six facets of extraversion, namely:

- *Activity:* Active, energetic people have high pace and powerful movement. They need to be busy and radiate a feeling of energy. They have a busy and hasty life.
- *Assertiveness:* Assertive people are dominant, self-confident and controlling. They talk without hesitation and often lead groups.
- *Excitement-seeking:* Excitement seekers desire adventure, stimulation, and action. They like bright colours, noisy environments, and prickly sensations.
- *Gregariousness:* Gregarious people prefer the company of others. They seek out others and like crowds and group activities.
- *Positive emotion:* People with positive emotion have fun, and feel happy and joyful. They laugh easily and are often cheerful and optimistic.
- *Warmth:* Warm people desire to form emotional bonds with others by showing warmth and affection. They are friendly and show that they genuinely like others.

These facets can provide interesting information on their own but should always be considered in relation to the other facets and the domain as a whole [8]. Low scores on a facet do not indicate the opposite of the facet, just the absence of the tendencies of that facet. For instance, low positive emotion does not mean unhappiness, just an absence of positive emotion.

Player Modelling versus Player Profiling

Player modelling is a technique used to learn a player's tendencies through automatic observation in games [26]. The technique can be used to improve gameplay by, for example, adjusting difficulty or storyline to the player's preferences.
The origin of player modelling is found in the domain of classic board games under the name of opponent modelling. It was simultaneously discovered in Israel and the Netherlands [13]. The goal of opponent modelling was to model the opponent's decision making process in order to make the best counter moves.
Opponent modelling spread to modern computer games as a means of calculating the best way to defeat opponents. As in classic games, opponent modelling tried to model the opponent's decision making strategies in order to make the best moves. Recently this goal has shifted. The emphasis is no longer on making the strongest moves but rather it is on increasing entertainment [2]. A good example of player modelling attempting to enhance the entertainment of games is the research by Thue [26] and by El-Nasr [14], in which player models are used to adapt the story and action in the game in order to fit the player's preferences.
The major differences between player modelling and player profiling lie in the features modelled. Player modelling attempts to model the player's playing style, while player profiling attempts to model the player's personality. The models produced by player profiling are readily applicable in any situation where conventional personality models can be used. Player profiling is also supported by a large body of psychological knowledge.

EXPERIMENTAL SETUP

To test our hypothesis that a player profile can be constructed by automatically observing player behaviour in a game, we developed a game using the Neverwinter Nights environment. Neverwinter Nights is particularly suitable for this purpose, as it comes with a powerful, easy-to-use toolset that allows the creation of large virtual worlds with social interaction and conversation. It also allows for the logging of player behaviour and choice.
We created a short story for the game that the player experiences. Playing through the story takes about half an hour. The story starts with a little girl asking the player to deliver a message to the king. The road to

the king is filled with several obstacles and encounters including: a beggar, several guards, a cleric, and several townspeople. Finally, the player will meet the king, and the game ends upon delivery of the message.

Test items

It was impossible to directly convert items of the existing personality questionnaires into game test items. The NEO-PI-R asks introspective questions *about* behaviour. We needed to construct in-game situations in which the player had the opportunity to display actual behaviour. Our primary source of test item guidelines was Costa and McCrae [7]. Items were based on NEO-PI-R items as well as on real life situations that were expected to elicit extravert and introvert behaviour. The items were designed to give the players a broad range of possible behaviours to facilitate them in acting in a personal and natural way.

Items were divided into three categories: choice and **A**ction, implicit **B**ehaviour, and **C**onversation. These categories were guidelines in creating items for different types of behaviour. We attempted to create at least one item in each category for every facet of extraversion.

- *Choice and Action* (A) encapsulates explicit and rational choice. In test items belonging to this category the player faces a number of options from which to choose. The choices represent options ranging from those an extravert would make to those an introvert would make.
- *Implicit Behaviour* (B) covers unconscious behaviour that is performed as an automatic preference. In test items belonging to this category no conscious choice is involved. They often involve measuring the time a player takes to make a decision to distance that is travelled within a certain amount of time.
- *Conversational items* (C) can be found in the conversations and the available choices therein. Differences between choices can be found in the way information is being conveyed or in styles of conversation and presentation.

All items are sorted by facet of extraversion. As listed earlier in this paper, the facets are Activity (Act), Assertiveness (Ass), Excitement Seeking (Exc), Gregariousness (Gre), Positive Emotion (Pos), and Warmth (War). The items are coded to be a combination of the facet measured and the category used. For example: GreB is an item measuring gregariousness (Gre) through implicit behaviour (B). The list of items follows below.

Activity (Act)
ActB_1: The time it takes the player to complete the entire experiment. Active people are expected to finish the game faster.
ActB_2: The player is forced to wait in a big, empty room for one minute. Active people are expected to cover more in-game distance during this period.
ActC_1: The player gets to respond to a request to wait. Active people are expected to respond negatively to this request.
ActC_2: The player is asked to confirm his response tor ActC_1. Active people are expected to stick by their choice.

Assertiveness (Ass)
AssA_1: The player gets a choice to lead or to follow. Assertive people are expected to desire to lead.
AssB_1: The player needs information from an NPC who is in a conversation. Assertive people are expected not to hesitate to interrupts the conversation.
AssC_1: The player gets a choice in how to address the king. Assertive people are expected to speak dominantly.
AssC_2: A beggar continues to hassle the player for gifts in an increasingly aggressive way. Assertive people are expected to stand up for themselves.
AssC_3: The player gets to confirm or retract his response to AssC_2. Assertive people are expected to stick by their choice.

Excitement-seeking (Exc)
ExcA_1: The player gets to change the decoration of a room. Excitement-seekers are expected to select bright colours.
ExcA_2: The player gets to choose music to play in the previously-mentioned room. Excitement-seekers are expected to prefer louder and faster music.
ExcB_1: The player gets to choose a costume to wear. Excitement-seekers are expected to prefer colourful clothes.
ExcB_2: The player gets a choice to fight with an annoying NPC or to flee. Excitement-seekers are expected to pick the option to fight.
ExcC_1: The player gets a choice to either finish the story or ask for more work. Excitement-seekers are expected to ask for more work.

Gregariousness (Gre)
GreA_1: The player gets to search information in either a bar or a library. Gregarious people are expected to prefer the bar.
GreA_2: The player gets a choice to continue on his own or in the company of a guard. Gregarious people are expected to prefer the company.
GreB_1: The player needs to approach some NPCs in a bar. Gregarious people are expected to approach larger groups of NPCs.
GreC_1: The player has a choice to explain his quest to a guard in terse or verbose terms. Gregarious people are expected to be more verbose.

Positive Emotion (Pos)
PosA_1: The player must comment on his chances to complete the task. Positive people are expected to respond optimistically.
PosA_2: The player gets to sell a drink to a guard. Positive people are expected to try to fetch a higher price for the drink.
PosC_1: The player gets to express his thoughts in different manners.
PosC_2: The player gets to reflect on his disposition in different manners. Positive people are expected to be more optimistic in their answers, and take an active interest in their conversational partner.

Warmth (War)
WarA_1: The player gets to donate some gold to a beggar. Warm people are expected to donate more.
WarB_1: The player gets a chance to converse with NPCs that are inconsequential to the story. Warm people are expected to address more of these superfluous NPCs.
WarC_1: The player gets to approach an NPC in either a straight-to-the-point or a more roundabout manner. Warm people are expected to be willing to chat a bit before getting to the point.

Experiment

We hypothesised that our test items have a correlation with the facet and extraversion scores of the NEO-PI-R. Therefore, they should function as predictors for extraversion and its facets. This is what our experiments wants to demonstrate.
The experiment was set up to have subjects take the extraversion part of the NEO-PI-R and play the game. In order to control for any possible order effects, the test subjects were divided into two groups that had a different order of playing the game and taking the test. At the end of the experiment, subjects were asked to fill in a brief questionnaire containing questions about topics that might influence the outcome of the experiment. These topics included age, sex, and experience with computers and games.
Upon entering the test room, participants were asked to read some instructions, and proceed with either playing the game or filling in the NEO-PI-R extraversion questionnaire depending on the group they were in. After finishing the first task the participant proceeded to perform the other part of the experiment.
For the questionnaire, the test subjects were asked to fill out the 48 questions of the NEO-PI-R that relate to extraversion. The time needed was approximately 10 minutes.
The game was presented with an instruction booklet asking participants to try to respond like they would in real life. Instructions on playing the game were included in the booklet. After reading the instructions the participant played the game which took between 30 and 40 minutes.
A pool of 24 participants, containing 18 males and 6 females, was tested. Ages ranged from 21 to 28 with a mean age of 24.2. Most participants were either students or former students. Subjects were randomly divided into two groups, one receiving the NEO-PI-R first and the game second and the other group received the game first and the NEO second. All subject data was processed anonymously.
The results were analysed with SPSS using a standard multiple regression analysis. The NEO-PI-R returns results on a one to five scale. Correlations were calculated using extraversion and the facet scores as dependent variables and the 25 game items as independent variables. Furthermore, regression analysis was conducted to inspect the relationships between the control variables and the extraversion scores.

RESULTS

The results of this experiments have been summarised in Tables 1 and 2. The tables contain the variables that have an effect size with a significance of 0.05 or smaller (the generally accepted significance level in psychology). For the variance of human behaviour, $r = .30$ is considered a medium effect while $r = .50$ is considered a large effect [4, 5]. For those interested in a complete overview of the results independent of significance, we refer to the work by Schreurs [23].
Table 1 contains the correlations between game items and the NEO-PI-R scores. Its columns stand for: activity, assertiveness, excitement seeking, gregariousness, positive emotion and warmth, respectively.
Table 2 contains the correlations beween the control items and extraversion and the game items. Its columns stand for: sex, age, education, experience with computers, experience with games, english language skill, ease of the controls, and clarity of the in-game missions.

Extraversion

The NEO-PI-R results show that our test subjects scored above average on extraversion. Scores range from 1 to 9 with 4 as the lowest measured score for our participants. Table 1 shows that significant correlation is shown between five of the game items and extraversion. Four of the correlations are positive and one is negative. All correlations are significant on a level of $p < 0.05$. Items ActC_1, ActC_2 and ExcC_1 were conversation items involving the willingness to wait, and item GreA_1 represents the choice between preference of going into the library or into the bar. Item ExcB_1 is the choice of colourful clothing which was scored from low being black to high being very colourful. Three of the five items showing correlation are conversation items, one

		Extraversion	Act	Ass	Exc	Gre	Pos	War
ActC_1	r	.456	.474	-	-	.474	.373	.365
	p	.013	.010	-	-	.010	.036	.040
ActC_2	r	.439	-	-	-	.650	-	-
	p	.016	-	-	-	.000	-	-
AssA_1	r	-	-	-	-	.348	-	-
	p	-	-	-	-	.048	-	-
AssB_1	r	-	-	-	.369	-	-	-
	p	-	-	-	.038	-	-	-
ExcB_1	r	-.409	-	-.434	-.390	-	-	-.389
	p	.024	-	.017	.030	-	-	.030
ExcC_1	r	.455	.394	-	-	-	.360	-
	p	.013	.028	-	-	-	.042	-
GreA_1	r	.498	-	-	-	-	.437	-
	p	.007	-	-	-	-	.016	-

Table 1: Correlations between NEO-PI-R scores and game items

being an implicit and one being an explicit choice. None of the 20 other game items showed any correlation sufficiently high to be significant.

While only 20% of our test items demonstrated correlation with extraversion, this result at least shows that it is possible to measure extraversion by observing player behaviour in a game. Our expectation was that each of the items would correlate with their given facet. However, we found that this is not the case. Items ActC_2, AssA_1, AssB_1, ExcC_1 and GreA_1, while showing correlation with some of the facets, do not display the expected correlation with their corresponding facets. Each facet has at least two items correlating with it. Inter-facet correlations show that some of these correlations are lower than in the questionnaire.

Control Questions

Table 2 shows that a large number of effects were found in the control questions. Elements such as age, sex, experience with computers and games, and skill of interacting with the game seem to be correlated with many of our test items and even with extraversion itself. For instance, it seems to be the case that experience with games is indicative for lower extraversion scores, which underlines the stereotype of the introverted gaming nerd. This means that values for test items, facets, and extraversion might be derived not only from observing a player's behaviour in the game, but also from his handling and understanding of, and attitude towards the game. It also means that, in future work, we might need to correct the results derived on test items for the meta-information from the control questions.

CONCLUSIONS

The research goal was to make a test that measures extraversion and its facets in a virtual environment. In order to answer this question we created an item set in the game Neverwinter Nights using the aurora toolset. The items were based on the items of the NEO-PI-R and were divided into three categories: choices and actions, implicit behaviour, and conversation.

In order to answer the question of correlation between in-game behaviour and personality scores on the NEO-PI-R, the test was administered to a pool of 24 participants and yielded results in 25 different items. Results were analysed for correlations using regression analysis. Results indicate that it is possible to measure extraversion and its facets using behaviour in a virtual world. Five of our items had significant correlation to extraversion scores on the NEO-PI-R.

We may conclude that it is possible to measure extraversion using a virtual environment. We currently lack evidence indicating whether a virtual world measurement or NEO-PI-R measurements reflect real life more accurately. This research provides a basis for future research in this field.

Future Work

In future work we will expand our research to include the other four traits of personality. There is also a need to compare the predictiveness of player profiling to written personality tests. Furthermore, in future work we will not design our test items by hand, but will attempt to discover them automatically by registering substantial volumes of game-playing data and correlating these with NEO-PI-R results.

ACKNOWLEDGEMENTS

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		Sex	Age	Edu	ExpC	ExpG	Eng	Eas	Cla
Extraversion	r	-	-	-	-	-.417	-	-	-
	p	-	-	-	-	.021	-	-	-
ActC_2	r	-	.344	-	-.364	-	-	-	-
	p	-	.050	-	.040	-	-	-	-
ExcA_1	r	-.462	-	-	.518	.469	-	-	.518
	p	.011	-	-	.005	.010	-	-	.005
ExcB_2	r	-	-	-	-	.347	-	.356	-
	p	-	-	-	-	.049	-	.044	-
ExcC_1	r	-	-	.364	-	-	-	-	-
	p	-	-	.040	-	-	-	-	-
GreA_1	r	-	-	-	-	-	-	-.420	-
	p	-	-	-	-	-	-	.021	-
GreA_2	r	-	-	-	-	-	-	.394	.393
	p	-	-	-	-	-	-	.029	.029
GreB_1	r	-	-	-	-	-	-	.353	-
	p	-	-	-	-	-	-	.045	-
GreC_1	r	-	-	-	-	-	.376	-	-
	p	-	-	-	-	-	.035	-	-
PosA_1	r	-	-	-	-	-	-	-	.360
	p	-	-	-	-	-	-	-	.042
PosC_2	r	-	.355	-	-	.360	-	-	-
	p	-	.044	-	-	.042	-	-	-
WarC_1	r	-.376	-	-	-	-	-	-	-
	p	.035	-	-	-	-	-	-	-

Table 2: Correlations between control questions and game items

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AN APPROACH TO PROVIDING FEEDBACK AT THE DESIGN PHASE IN GAME AUTHORING TOOLS

Fergal Costello
National University of Ireland, Galway
Galway
Ireland
E-mail: fergal.costello@gmail.com

Colm O'Riordan
National University of Ireland, Galway
Galway
Ireland
E-mail: colm.oriordan@nuigalway.ie

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ABSTRACT

In this position paper, we propose and discuss the development of an authoring tool to aid designers in their jobs of creating game worlds. The long term goal of this research is to present mechanisms that can be used to measure the features of the design characteristics of games. The proposed tool should offer ongoing informative feedback to the level designer; this feedback will relate to the difficulty (and ideally to how interesting players might find the game) in the current level to aid the designer gauge the design. Currently, we choose an exemplar game (intruders and patrollers in a grid with shapes offering 'cover' to the agents in the game) and propose a set of measures that may inform the designer as to the effect of changes they make on the current difficulty of the level.

INTRODUCTION

In an industry where the budget of *AAA g*ame titles can run into millions of dollars, rapid prototyping is more important now than ever. In this paper, we propose a framework where the design of a game can be measured during the design phase prior to fully prototyping the game. We aim to measure, during the design phase of the game, aspects such as fun and interestingness. These can be difficult terms to try and define (Hunicke et al. 2004), as notions of fun and interestingness are often highly subjective. However we believe that we can provide some insight into these terms through measuring notions of difficulty of a game or level.

In this paper we present a mechanism by which an abstract game can be designed by a designer in which feedback can be given on how difficult this game may be for players, thus giving designers early feedback in the development lifecycle.

The remainder of this paper is as follows: the next section describes the current development process in the games industry and discusses some current work in notions of difficulty. The subsequent section discusses a test bed for testing our hypothesis by presenting an abstract game and a set of proposed measures to capture aspects which we believe influence the level of difficulty inherent in a level. Finally, we present the future goals of this research.

BACKGROUND

Industry practice for creating game levels follows an iterative process, which may consist of the following phases: conceptualise, plan, execute and refine (Castillo 2008). In this approach, an idea is conceived (conceptualisation), expounded on paper (planning), built in a level editor (execution) and finally touched up (refinement). With this process, it is only from the execution stage onwards that play testing can occur, allowing feedback into the planning phase. Following the refinement stage, dedicated play testing sessions can occur, where members of the target audience play through the level. In this play testing, gamers' experiences are monitored and recorded to give the designers an insight into the quality of the level. Based on this information it may be necessary to refine the level, or in the worse case, completely redesign it. This can be an expensive process. As is true of all software development processes, any refinements that have to be undertaken later in the process have a larger associated cost, than ones that can be undertaken earlier in the project life cycle.

RELATED WORK

One of the related fields to this research is Dynamic Difficulty Adjustment, which modulates in-game systems to respond to a particular player's abilities over the course of a game session (Hunicke 2005). Hunicke presents a system, termed Hamlet, which maps the state of the game world to a set of adjustment actions (by using an evaluation function and an adjustment policy) to intervene on behalf of the player. Generally speaking, this approach adjusts the game mechanics such as the damage the player can inflict, and the amount of damage enemies can inflict upon them, enemy accuracy, spawn locations etc., in order to better suit a player's abilities. In dynamic scripting, an unsupervised online learning technique (Spronck et al. 2004a), scripts of rules are extracted from a rulebase as NPC opponents are created. The probability a rule is selected for use in a script is proportional to how well the rule performed previously. Coupled with difficulty scaling (Spronck et al. 2004b), the game can be adapted automatically, to modify the challenge posed to the human player, by further enhancing the probabilities by which rules are selected. The main difference between these two approaches and ours, is that we discuss methods for measuring difficulty at design time, as opposed to presenting a run-time solution.

There have been several efforts in the literature to measuring interestingness in computer games. Yannakakis and Hallam present work that focuses on the contributions made by an opponent's behaviour to the entertainment value of a game. They argue that because 'interest' and 'enjoyment' aren't explicitely defined, there is no evidence that an opponent's learned behaviour is fun to actually play against. With this in mind, they use Artificial Neural Networks (ANNs) and Fuzzy ANNs to model player satisfaction (interest) and they investigate quantitatively how qualitative factors such as challenge and curiousity contribute to entertaining experiences (Yannakakis and Hallam 2006). The task of measuring and estimating the difficulty of a problem has been tackled in a range of domains. The analysis of fitness landscapes in evolutionary computation is one such approach (Tomassini et al. 2005). In this work and other works in a similar vein, the notion of difficulty is tied explicitly to the fitness landscape. If simple perturbations/mutations lead to solutions of similar fitness, then the landscape can be easily climbed and hence the problem is not overly difficult. This inherently captures notions of deceptive problems (Horn and Goldberg 1994) whereby evidence in a learning framework leads the solution in a certain direction (a local optimum) away from the actual global phenomenon. Similarly in a game scenario, if minor changes in behaviour by a player result in radically different outcomes, then it is a difficult landscape. Furthermore, if the evidence in a level guides the player away from the optimal behaviour, then playing that particular game level may constitute a deceptive problem.

THE GAME AND AUTHORING TOOL

We propose an abstract game that we use to test our hypothesis. The simpler the game design, the more game genres it can abstractly capture. However, some domain representation is necessary to make sure we develop an apt design particular to a specific domain. As such we focus on a game that consists of a single intruder trying to traverse an environment, while trying to stay out of sight from guards. This maps quite well to many genres of computer games, first and third person shooters, stealth, role playing games etc, which normally consist of the player fighting against a larger force of enemies. The intruder in this specification would be analogous to the player. This is an abstract game representation that has received much attention in recent years (Basilico et al 2009; Agmon et al 2008).

The world in which the agents live is a grid of cells. The cells themselves have no intrinsic meaning and can vary according to designers' needs. They can represent one square meter, whole rooms, or even whole landscapes. Should an agent be seen by the guards, then the game is over and the agent must restart the level. This is not a game play feature of most computer games, particularly the ones mentioned above, with the exception perhaps of certain stealth games, but as a constraint in our game it is useful as a feature to measure difficulty correctly, which is discussed in the next section. The guards have a simplified perception model, allowing them to perceive the current cell they are in with a certain probability. They also have an associated path, which acts as their patrol routes. Finally, to complete the environment, the designer can lay the following types of nodes: starting point, target objective, and cover.

- Starting Point: The starting point is the point at which the intruder enters the environment. There can at most be one of these in any environment.

- Target Objectives: The target point is the point to which the intruder must travel.

- Cover: To aid in the intruder reaching their goal we add cover nodes to the environment which provide them with areas in which to hide from the guards. When an intruder occupies this node they are hidden from any guards that can otherwise see them. This is analogous to the Cardboard Box in the popular Metal Gear Solid franchise (Kojima 2008), but unlike metal gear, our cover nodes are static.

MEASURING DIFFICULTY

In this game, an intruder must reach the target while avoiding being seen/captured by one of the patrollers. Objects may be placed by the designer on the grid to give the intruder places to obtain cover. Multiple paths exist which the intruder may follow. In this paper, we propose a set of measures to attempt to capture the inherent difficulty of the created level. This is clearly a difficult problem, as the inherent difficulty may be characterised by a deceptive non-linear function of the properties of the level.

If there is no patroller in the gird, an intruder can merely traverse towards the goal cell. This is clearly an easy level. Conversely, we can also define an impossible level (maximum difficulty) where we place patrollers on all cells. In between these unrealistic extremes, there exist myriad possible configurations which will have an inherent level of difficulty in identifying a safe or optimal route from the starting position to the goal state. There are many factors which should be considered in any approach to measure difficulty in a level.

In the simpler cases, one can consider the behaviour of the patroller and measure the difficulty involved in inferring or calculating the optimal game-theoretic response to that particular configuration. There have been several interesting approaches in this manner but they have their associated limitations - firstly, computing optimal responses is difficult and as the complexity of the environment grows such calculations become computationally intractable; secondly, identifying the optimal game theoretic strategy does not necessarily gain us any insight into what actual human players may find difficult; for many games it is has been well documented that humans often act in a manner which deviates radically from the game-theoretic predicted behaviour.

Rather than attempting to adopt such an approach, we aim to initially define a number of measures that may capture notions of difficulty. Further work will be to learn how to best combine these measures to gauge difficulty; this learning will be guided by monitoring users' behaviours on a number of levels.

There are, in this abstract game, several obvious factors which influence the level of difficulty in the game that may be used to estimate difficulty. These include:

- number of patrollers present in the environment
- their ability to perceive the intruder
- the number of paths from the starting state the goal state
- the difficulty of these paths (level of cover, the number of nodes on this path covered by the patroller etc.)

We wish to derive functions with the above four as inputs returning as output, the level of difficulty. Our current implementation returns a vector of values corresponding to the above which will give the designer immediate feedback, i.e. measures of the number of patrollers, values indicating their perceptive abilities (function of both their basic perception and a score corresponding to their patrol movement), number of paths and their lengths and finally a measure corresponding to the level of danger on the paths.

CONCLUSIONS AND FUTURE WORK

This paper presents a proof of concept tool that enables designers to create abstract levels that conform to a set of simple game mechanics and which gives feedback on the design characteristics of the environment. This feedback is useful in game design as it allows for early validation of game levels, which could prove beneficial to development studios. However, as this is research is currently at an early stage, much future work is necessary. In this paper we present mechanisms for measuring difficulty based on a small parameter space. In future work we will be looking at increasing this parameter space as well as creating and comparing varying heuristics. Having explored these heuristics and measured their correlation with users' experiences, we hope to further explore the heuristics by learning which combination best approximates the users' subjective experiences in terms of difficulty and interest. This in itself gives way to interesting crossover with the traditional approach to modelling players.

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BIOGRAPHY

FERGAL COSTELLO received his B.Sc. degree in Information Technoloy from the National University of Ireland, Galway, in 2005. Following that he spent 3 years working various contract positions as a software developer. He has since returned to his alma mater to pursue a PhD in the field of Computational Intelligence in Computer Games and is funded for such by the Irish Research Council for Science, Engineering and Technology.

COLM O'RIORDAN lectures in the Department of Information Technology, National University of Ireland, Galway. His main research interests are in the fields of agent based systems, artificial life and information retrieval. His current research focuses on cooperation and coordination in artificial life societies and multi-agent systems.

GAME GRAPHICS

RENDERING WATER AND LAND INTERACTION USING A SPRING SYSTEM

Yifan Sui
Andrew Davison
Department of Computer Engineering
Faculty of Engineering
Prince of Songkla University
Hat Yai, Songkla, Thailand
E-mail: suisuige@yahoo.com.cn
E-mail: ad@fivedots.coe.psu.ac.th

KEYWORDS
Spring system, wave curve, collision detection, mesh, height value.

ABSTRACT

This paper describes a spring-based model for the interaction of water and land, which reconciles realism and fast rendering. The system controls the motion and interdependences of water vertices utilizing two kinds of springs and collision detection. As a consequence, a wave's movement affects the waves around it, and a wave 'hits' the land, rebounding with a suitably changed height and velocity.

1. INTRODUCTION

The rendering of large areas of water is well understood (Tessendorf 1999; Johanson 2004), and has become common in games. However, there is little physics-based interaction with the shoreline as waves move up and down, and generate spray and foam.

Most 3D systems employ Perlin noise functions (Johanson 2004), although some ocean effects (such as refraction and obstacle collision) have been utilized (Iglesias 2004). For instance, Peachey (Peachey 1986) and Fournier and Reeves (Fournier and Reeves 1986) model waves that approach and break on a sloping beach. However, there is no real force connection between the water and the land, since the wave profile is changed according to wave steepness and water depth.

Foster and Fedkiw (Foster and Fedkiw 2001), and Enright, Marschner and Fedkiw (Enright et al. 2002) simulate breaking waves using a combination of textures and particles. The computational cost of the former is several minutes per frame on a PentiumII 500MHz.

Mass-spring systems are arguably the simplest and most intuitive of all deformable models for simulating fluid (Nealen et al. 2006). Using a spring system to simulate the motion of water over a coastline is compulationally feasible, as this paper illustrates.

2. WAVE CURVES AND THE COASTLINE

The land is a 128*128 textured mesh contoured with a height map. The waves in the water mesh are modeled using Peachey's method (Peachey 1986), so the height of the water vertices varies as a sum of water level and wave height. The color of each vertex is based on its current height. Our prototype was created using JOGL (a Java binding for OpenGL (JOGL, 2009)). Figure 1 shows a screenshot of the model with its elements.

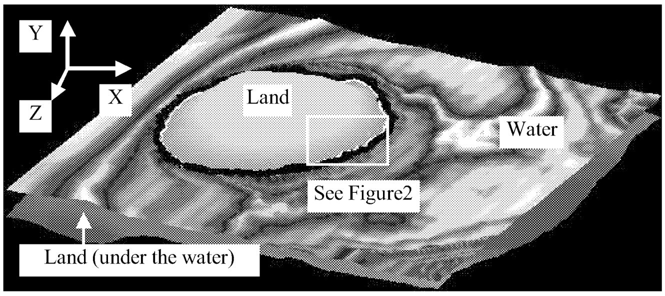

Figure 1: An overview of the model.

The coastline is the series of water vertices that are closest to the land, (see Figure 2). Wave curve 1 is the line of vertices one mesh interval away from the coastline, wave curve 2 is the line of vertices one mesh interval away from wave curve 1. In this way, we define a coastline and four wave curves, which are linked with springs as explained in section 3.

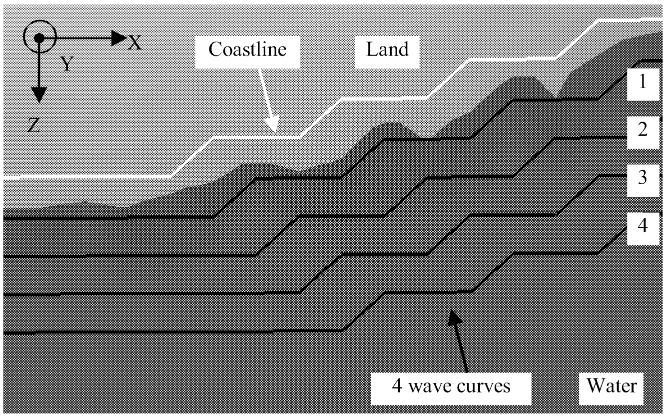

Figure 2: A view of the model from overhead, showing the coastline and four wave curves.

2.1 Vertical Water Mesh Movement

In shallow water, the water vertices move up and down by employing a summed combination of four versions of the height function (1):

$$Y_i = 8*(\frac{\sqrt{x_i^{\,2}+z_i^{\,2}}}{L_i}-\frac{t}{T}-\frac{1}{2})^2-1 \qquad (1)$$

where i is the index of a vertex, Y is the wave height of the vertex, x and z are the (X, Z) coordinate values of the vertex, t is the time which increases by 0.1 in each frame. T is the period of the function, equal to 80 frames to look realistic. L is the wavelength at the vertex position.

When a wave enters the shallows, where the depth is less than one-twentieth of the wavelength, the wave length L is determined by Equation (2):

$$L = T\sqrt{gd} \qquad (2)$$

where d is the depth of water, and g the gravity (Alonso and Finn 1992; Sverdrup 2006).

Figure 3 illustrates how these equations affect the height of the water mesh as it approaches the shallows.

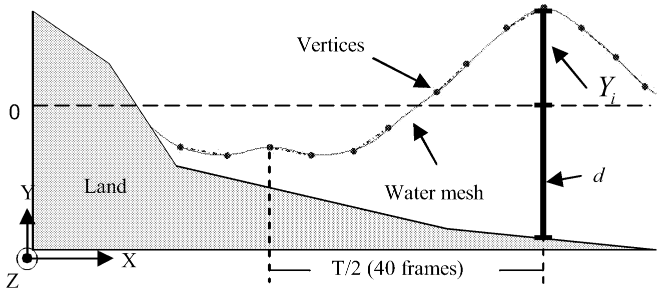

Figure 3: The height of water vertices in shallow water.

2.2 The Coastline

The coastline is the line of water mesh vertices closest to the land mesh, as shown in Figure 2 and Figure 4.

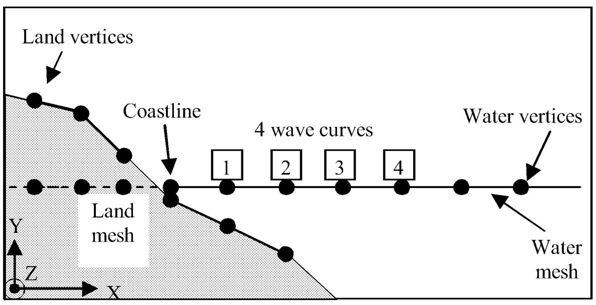

Figure 4: The position of the coastline.

The coastline boundary moves up and down due to waves, but doesn't shift in the X-Z plane.

2.3 Wave Curves

Wave curve 1 is the line of water mesh vertices adjacent to the coastline, but one mesh interval away from the land. Wave curve 2 is the line of water mesh vertices adjacent to wave curve 1, but one mesh interval further away. Wave curve 3 and 4 are calculated in a similar way. Our model is limited to four wave curves as a balance between interaction realism and computational efficiency.

Wave curves 3 and 4 can move in the X-Z plane, towards and away from the coastline. Each vertex in the curves has a movement direction pointing from its original position toward the nearest coastline vertex. The vertices of wave curve 3 can move up to the coastline, while the vertices of wave curve 4 can move up to wave curve 1 (see Figure 5). Wave curve 4 can not easily pass through wave curve 3. These restrictions on curve interaction produce realistic wave behavior, and are implemented using our spring system and collision detection, as detailed in sections 3 and 4.

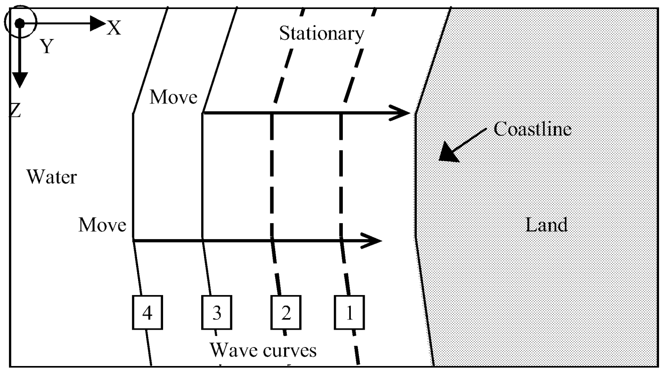

Figure 5: The movement of wave curves.

Wave curves 1 and 2 can not move in the X-Z plane, which means that the ebb and flow of the water against the coastline is driven by wave curves 3 and 4.

3. INTERACTION BETWEEN WAVE CURVES

The interaction between the water and land use *position springs* and *wave springs* to modify the X- and Z- velocities of the vertices in wave curves 3 and 4.

3.1 Position Springs

A position spring ensures that a vertex is pulled back to its original position after moving towards the land. Every vertex in wave curve 3 and 4 has its own position spring.

Figure 6 shows a vertex N_s. At time 0, it is at its rest position, labeled as $N_{s,0}$. At time t, it has moved to be at position $N_{s,t}$. The position spring P extends from the $N_{s,0}$ rest position and will pull N_s back from its $N_{s,t}$ position.

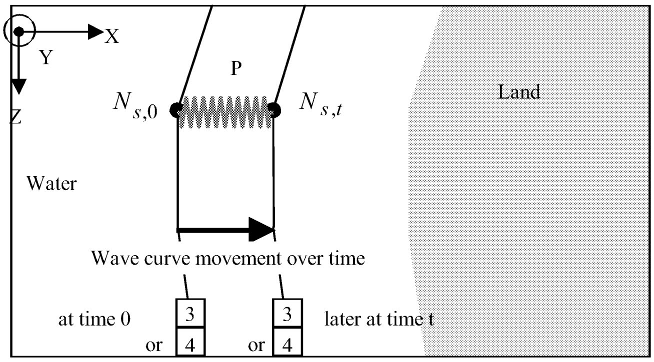

Figure 6: A position spring P for vertex N_s .

3.2 Wave Springs

Every neighboring pair of vertices in wave curves 3 and 4 are linked by a wave spring. For example, Figure 7 shows a wave spring W linking the vertices N_s and N_r of wave curves 3 and 4.

Wave springs help to deal with crossover behavior when vertices in wave curve 4 are moving faster than those in wave curve 3, and attempt to pass through it. Wave springs slow down wave curve 4 vertices as they approach wave curve 3.

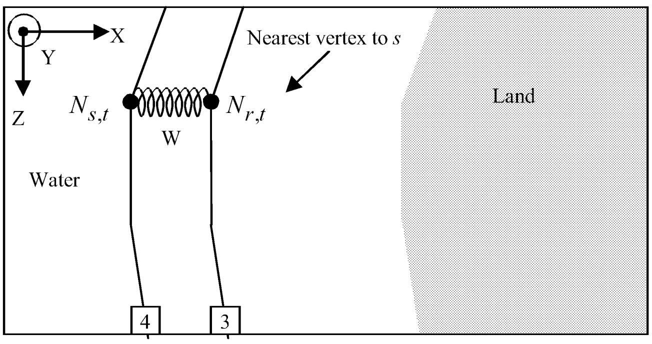

Figure 7: A Wave spring W between vertices N_s and N_r in wave curves 3 and 4.

4. COLLISION DETECTION

Our model deals with two kinds of collision:

1) between the water and the land, as represented by wave curve 3 and the coastline;

2) between waves, as represented by wave curves 3 and 4.

Our approach builds upon real time collision detection (Ericson 2005) by applying it in the context of our spring system.

4.1 Water and Land Collision

The collision detection algorithm is simplified by utilizing the coastline to represents the land, and wave curve 3 as the leading edge of the water.

Each coastline vertex is surrounded by a bounding sphere, whose diameter is equal to the initial inter-mesh spacing.

If a wave curve 3 vertex moves inside the bounding sphere of a coastline vertex, a collision has happened. The velocity of the wave curve 3 vertex is reversed, to make it head back towards its rest position.

Figure 8 shows a vertex N_s in wave curve 3. At time 0, it is at position $N_{s,0}$, then moves towards the coastline and 'hits' the coastline vertex C_p at time t. The velocity of N_s, $V_{s,t}$, is reversed to be $-V_{s,t+1}$ at the next time interval t+1. A scaling factor also reduces the velocity, to take account of the way a wave loses energy when rebounding.

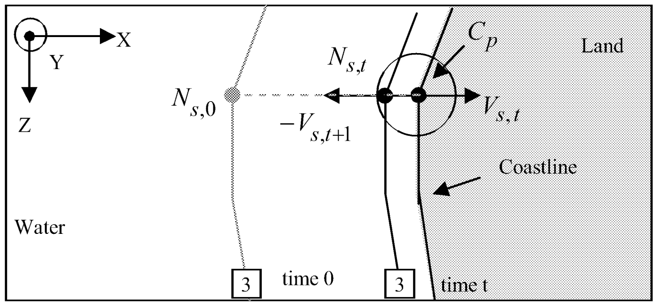

Figure 8: Water and land collision.

4.2 Wave Collision

As explained in section 3, wave springs implement crossover slowdown, but if the velocity of wave curve 4 is much higher than wave curve 3 then crossover could still occur. This is prevented by collision detection between the vertices of wave curves 3 and 4. When a vertex in wave curve 4 hits wave curve 3, their velocities are equalized, so the two wave curve segments will move together, or perhaps separate. This is implemented by updating the velocity of the vertex in wave curve 4 and its nearest neighbor in wave curve 3.

Figure 9 shows the case when vertex N_s is about to hit the wave curve segment V1-V2. A collision is detected between N_s and the segment, and the velocities of N_s and V2 are modified.

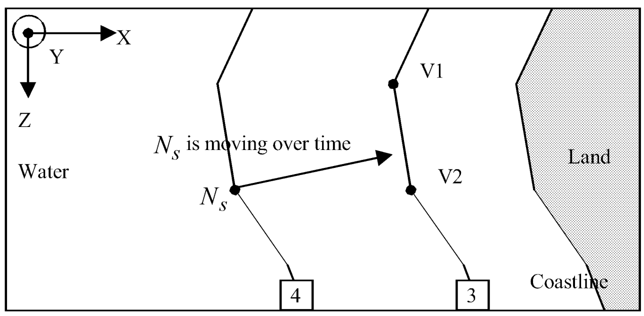

Figure 9: Wave Collision.

The overall behavior of N_s will be more complicated than this (and more realistic) by also being affected by a wave spring linking it to V2 (its nearest neighbor in wave curve 3), which is not shown in Figure 9.

5. TESTING

On a single core 1.73 GHz 2GB DDRII-533 RAM Intel GMA 950, the model executes at about 70 FPS; on a two-core 1.86 GHz 1GB DDRII-533 RAM X300 graphics card, about 140 FPS are achieved, and our OS both are Windows XP SP3 Professional. When we extend the mesh size to 256*256, the model executes on two machines at about 54 FPS and 26 FPS.

Figure 10 is a cross-sectional view of the model showing water moving towards the land.

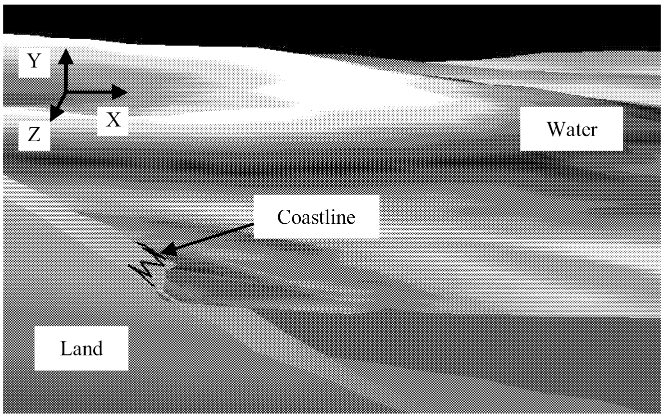

Figure 10: Water moving towards the land.

Figure 11 shows the land, coastline, and wave curves of Figure 10 from overhead.

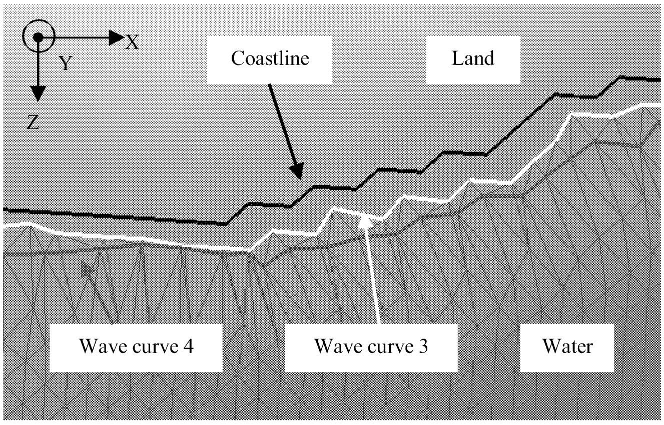

Figure 11: Wave curves moving towards the land.

Figure 12 shows the scene later after the water has rebounded from the land.

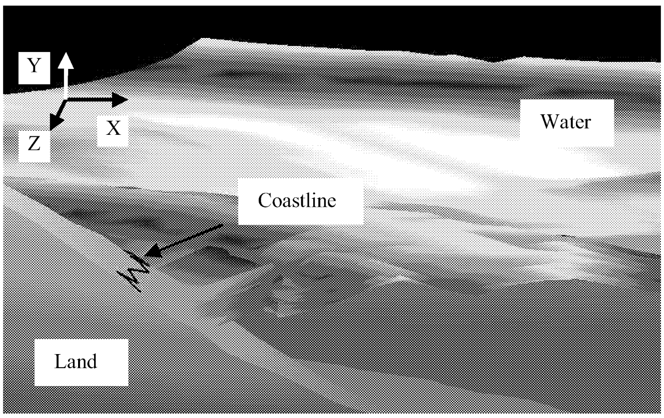

Figure 12: Water retreating from the land.

Figure 13 is a view of Figure 12 from overhead. It shows that the position springs in wave curves 3 and 4 are drawing their vertices back to their rest positions. The interaction between wave curves 3 and 4, as controlled by wave springs and collision detection, is also visible.

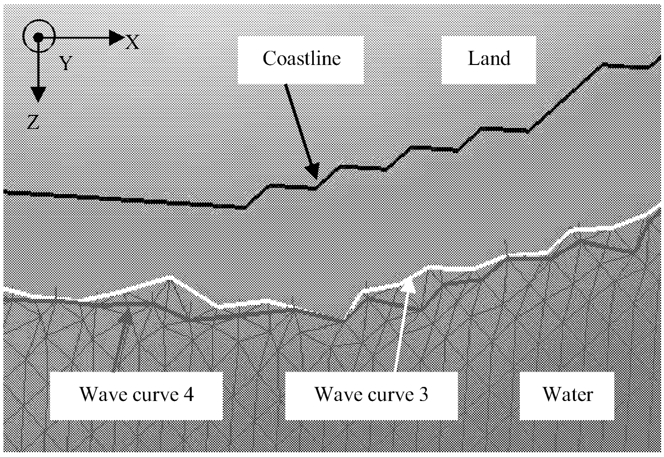

Figure 13: Wave curves rebounding from the land.

Figure 13 illustrates that crossover still occurs, as it does in real waves, but is a rare event, and is soon followed by the waves either moving in unison or pulling apart.

6. CONCLUSIONS

Our system models the interaction of water and land using a novel combination of two types of springs (position and wave springs) and two forms of collision detection. The simulation exhibits realistic behavior between waves and the coastline, and between the waves themselves, while rendering at very acceptable speeds. The spring system is relatively simple to understand and fine-tune, and is based on the physical characteristics of real waves.

We plan to improve the visualization by adding particle-based foam and spray. It will appear on wave crests, the coastline, and wherever collisions occur.

When the water recedes from the land, the exposed areas should look wet. We intend to color these areas accordingly, and let the color gradually fade over time.

Our long term goal is to use this approach to model Tsunami-land interaction. The spring system will need to be modified to deal with large waves (over 30m in height) moving at very high speeds (more than 800 km/h) (Kaitoku 2008). The coastline interaction will need to be more complicated to deal with the way a tsunami can wash over a large body of land.

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Responsive Real-Time Simulation of Ground Vegetation for Games

Orthmann Jens
Computer Graphics Group
University of Siegen
56076, Siegen, Germany
orthmann@fb12.uni-siegen.de

Christof Rezk Salama
Mediadesign
University of Applied Sciences
40227, Düsseldorf, Germany
c.rezk-salama@mediadesign-fh.de

Andreas Kolb
Computer Graphics Group
University of Siegen
56076, Siegen, Germany
kolb@fb12.uni-siegen.de

1 INTRODUCTION

Large natural environments are often essential for todays computer games. Interaction with the environment is widely implemented in order to satisfy the player's expectations of a living scenery and to help increasing the immersion of the player. Within this context our work describes an efficient way to simulate a responsive grass layer with todays graphics cards in real-time. Clumps of grass are approximated by two billboard representations. GPU-based distance maps of scene objects are employed to test for penetrations and for resolving them. Adaptive refinement is necessary to preserve the shape of deformed billboards. A recovering process is applied after the deformation which restores the original that is to say the undeformed and efficient shape. The primitives of each billboard are assembled during the rendering process. Their vertices are dynamically lit within an ambient occlusion based irradiance volume. Alpha-to-Coverage completes the illusion as it is used to simulate the semitransparent nature of grass.

2 MOTIVATION

State-of-the-art 3D games and realtime simulations demonstrate the power of currently available graphics hardware for rendering exciting natural sceneries in real-time. As nature scenes often include a lot of plants (blades of grass, shrubs, trees etc.) the rendering of a large number of them is still challenging. Furthermore, they cannot be displayed with complex geometry in real time. Many of the approaches make use of billboard representations to preserve the real-time constraint while leaving out user interaction.

In general, static level design is more and more replaced by dynamic environments that can be modified in real-time throughout the gaming process. Due to the fact that natural phenomena are better approximated in the game, the player feels a higher immersion while playing [McM03]. Consequently, the dynamic environment is becoming a part of the game logic: Trees are chopped to clear the path and objects need to be moved in order to fulfill quests. The more the realism of the scene is enhanced the more of the player's expectations are satisfied.

Following this trend, our paper takes dynamic environments one step further by integrating responsive real-time simulation of ground vegetation. We propose a highly efficient technique for GPU-based simulation of responsive grass billboards. Our implementation targets Shader Model 4 graphics boards, including geometry shaders and stream output. The collision detection with dynamic scene objects, the response and the recovering are directly simulated on the GPU. An adaptive geometrical representation of the grass guarantes a pleasing visual rendering in conjunction with a high performance. Thus, the responsive grass approach has the potential to significantly improve the challenges in game play of modern games and may lead to a better perception of interactive environments.

The structure of this paper is as follows: in Section 3, an overview of the related work on grass simulation is given, followed by a overview of the responsive grass system in Section 4. Section 5 proposes the procedural generation process of the grass layer. In Section 6, the realization of the collision system is described. The rendering of the grass layer is presented in Section 7 and the results and performance of our technique is discussed in Section 8. Finally, Section 9 concludes the presented responsive grass approach.

3 RELATED WORK

In recent years, most research applied to natural sceneries focuses on the rendering and animation of a great number of plants. For volumetric representations, as proposed in [BCF$^+$05, BPB06], collision detection and reaction is awkward to handle. Guerraz et al. [GPR$^+$03], however, presented an approach which allows an object to tramp on the grass layer. A primitive is moved along the character's trajectory while affecting the procedural animation process of the grass. Nevertheless there still is no possibility to react to collision, based upon the object's geometry. The reuse of grass tiles amplifies the problem of collision response. Billboards which represent a number of grass blades as a semi-transparent 2D texture are more suitable in that case. The billboard representations stored in a single vertex buffer [Wha05] are efficiently animated [Pel04, Bot06, Sou07] and rendered [BCF$^+$05] on the GPU.

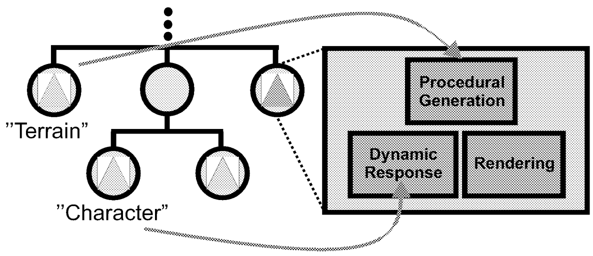

Figure 1: The system for responsive grass.

As the collision detection for grass is less explored, related algorithms on a wider range are examined. In case large dynamic geometry is stored and processed completely on the graphics memory, image-based techniques [VSC01, KP03, HTG04, KLRS04, GLM05, Sat06] are proven to solve the collision tests very fast. Kolb et al. [KLRS04] offered an approach to collision detection using distance maps which are fully generated and accessed on the GPU. A lookup into each distance map is used to decide whether a vertex lies inside or outside of a object. Using the normal information the vertex can be translated in the direction of the shortest way out of the object. Their approach fits best in case all computations, including the collision reaction, are done on the GPU.

Cloth models [Pro95, FGL03, Zel07] are applied in order to overcome the problems in the context of the collision reaction. Fuhrmann et al. [FGL03] replace the cloth forces [Pro95] by several length constraints along the connection of two particles in order to avoid problems which are caused by large time steps. Zellner [Zel07] entirely offloads the model to the GPU and handles the recursion via the stream output stage.

Regarding high quality rendering of massive material scenery a precomputed irradiance volume is employed [Oat06, CL07]. The volume stores the irradiance information of the whole static scene. Interpolation within the volume allows us to dynamically lit the grass billboards at runtime similar to the two-sided lighting proposed by Kharlamov et al. [KCS07]. The Alpha-To-Coverage feature of todays graphic cards [Mye06] avoids expensive depth-sorting of the semi-transparent billboards while maintaining a consistent visual appearance similar to David Whatleys procedure [Wha05].

4 SYSTEM OVERVIEW

The responsive grass system is seamlessly integrated into a game engine. A grass node can be added to an arbitrary part of the graph and comprises the following components as shown in Figure 1:

- **Procedural Generation:**
  For a given terrain mesh, a geometry shader automatically generates billboards for grass blades. This geometry shader is executed once for each tile of terrain, and the results are stored in local video memory using the stream-out capabilities. An octree structure is generated above the grass layer. We describe the process in detail in Section 5.

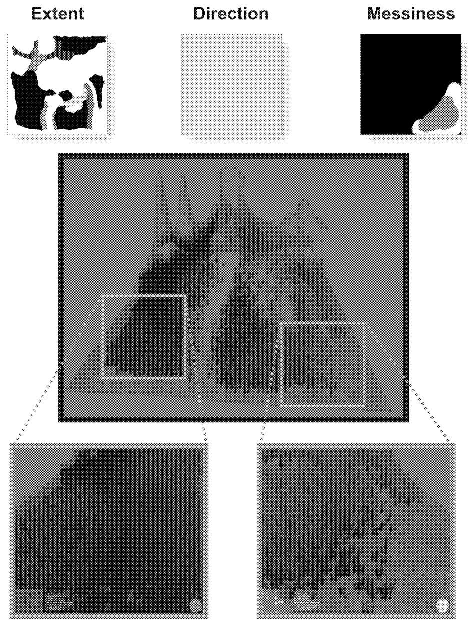

Figure 2: The top row shows the texture images for the extent, direction and messiness and underneath the resulting plant cover is displayed.

- **Dynamic Response:**
  A CPU-based broad phase working on the spatial organized grass tiles and a GPU-based narrow phase working on the generated grass billboards constitute the responsive component. During this stage the grass layer will be adapted whenever external forces like colliding scene objects make it necessary. This process which is implemented within the collision system is outlined in Section 6.

- **Rendering:**
  Deformed or undeformed billboards are rendered based on the output of the collision system. With the knowledge of the occluders and the terrain precomputed occlusion volumes respectively irradiance volumes may be employed to integrate ground vegetation into a dynamic global lighting environment. We adapt such techniques for realistic rendering of dynamic ground vegetation as described in Section 7.

5 PROCEDURAL GENERATION OF THE BILLBOARDS

A clump of grass is represented by a semi-transparent textured quad. The individual billboards are created in a pre-processing step performed by the GPU. A set of

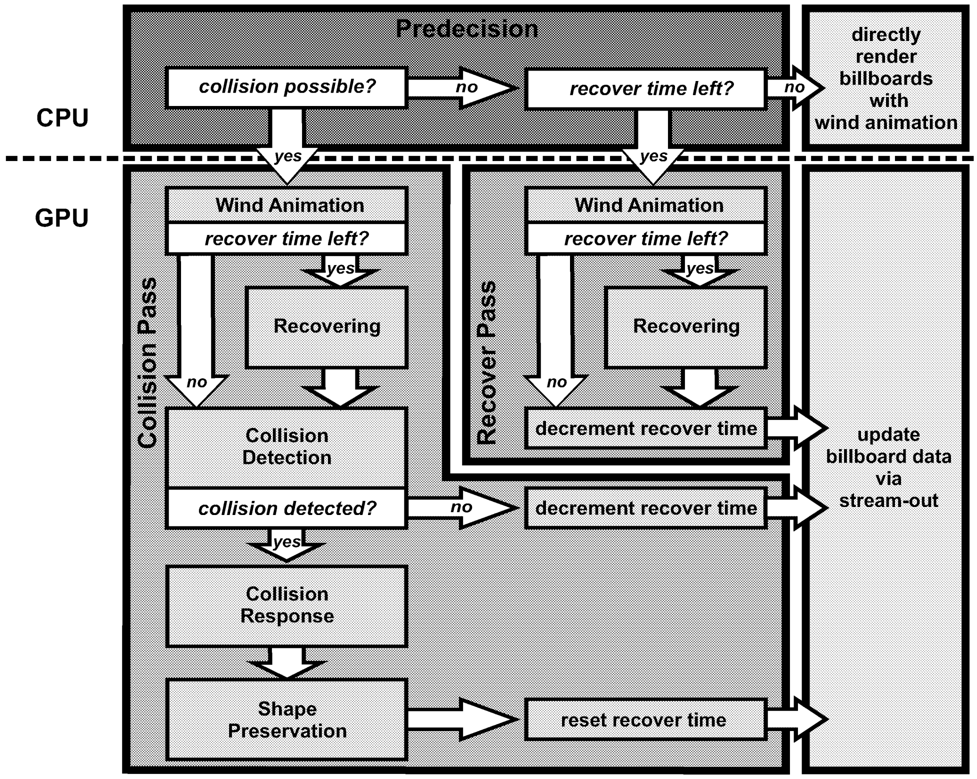

Figure 3: Flow diagram for collision detection, reaction and recovering.

texture images provides the information of the global layout of the grass layer as shown in Figure 2. These textures are in detail:

- a grayscale texture map which defines the regions of the plant cover (extent),
- a RGB texture which defines the direction to which the grass blades grow (for simplicity the direction is chosen to be the same for all grass blades),
- a grayscale *messiness* texture which defines the amount of randomness for the blades.

The geometry shader creates a randomized set of billboards representing the grass blades. Each billboard stores an orientation, a position, a collision state, and a texture index, addressing a 2D texture array, which stores different semi-transparent images of grass clumps. Each billboard is passed through the pipeline as a point primitive, which allows the different geometry shaders to handle its information en bloc during the collision handling and rendering. When the billboards are generated, they are streamed to one large vertex buffer [Wha05] to minimize subsequent render calls. For a coarse collision detection on the CPU, the terrain mesh is used to divide the set of billboards into an octree hierarchy. Each leaf node of the octree stores a range of indices into the vertex buffer of the billboards and state information described throughout the next section.

6 COLLISION SYSTEM

The pipeline of the collision system is outlined in Figure 3. Without collision, the billboard quads can directly be rendered. The upper two vertices of each billboard quad are transformed with a procedural wind animation based on a weighted sum of trigonometric functions with different frequencies [Pel04, Wha05, Bot06, Sou07]. The collision system is split into a CPU-based coarse handling and two GPU-based procedures, one for executing the collision test and response and one for performing the recovering. The different steps of the GPU-based collision handling are outlined in Figure 4.

6.1 Coarse Handling on the CPU

At each frame, the bounding volumes of all dynamic collision meshes are tested for collision with the axis aligned bounding boxes (AABB) of the octree containing the grass blades. According to the current state information and the results of the collision test, each node is marked as either *possibly colliding*, *non-colliding* or *recovering*. The geometry assigned to each octree node marked as *possibly colliding* is streamed through a collision pass on the GPU. A tile marked as *recovering* will stay active for a fixed amount of time after the collision when the object has left the AABB of the octree node. During that time a separate geometry shader recovers the original shape of the grass blades.

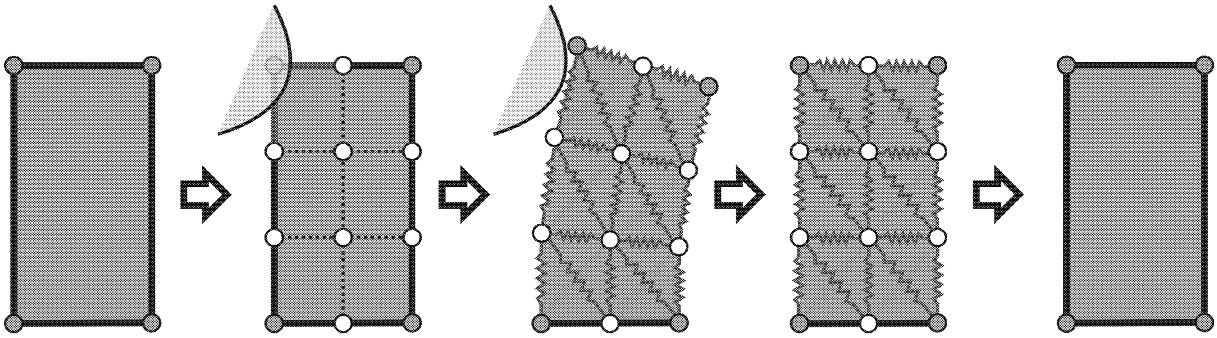

Figure 4: Collision detection, reaction and recovering for a single billboard.

6.2 Collision Detection

In the collision pass, a geometry shader receives all the vertex information of a potentially colliding billboard at once. The geometry shader computes the bounding sphere of the animated billboard and performs a collision test against the bounding spheres of the dynamic objects. These bounding spheres are managed in a dynamic texture resource, which is updated every frame. If the collision test is passed on the bounding sphere level, a second and more exact collision test is performed on a subdivided mesh of the billboard. The geometry shader determines for each vertex whether it lies inside or outside the dynamic collision object by performing lookups into the depth cube map [KLRS04] of the object. Dynamic objects capable of colliding with the plant cover are represented by depth cube maps for efficiency. These cube maps are computed by projecting the object's mesh onto the faces of a bounding cube and store the distance to the cube plane and the respective object normal in the four texture components as shown in Figure 5. They are updated for each frame to account for animated objects.

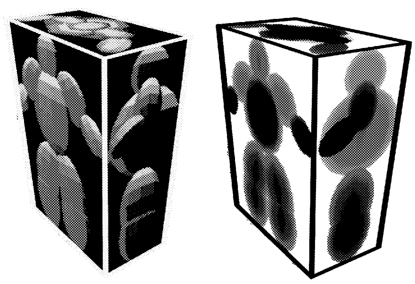

Figure 5: The depth cube map with surface normals.

6.3 Collision Response

If a collision has been detected, the vertex is moved out of the object's shape. Its position is translated along a normal vector $\mathbf{n}$ obtained from the depth cube map:

$$\mathbf{v} \leftarrow \mathbf{v} + s\,\mathbf{n}\,, \qquad (1)$$

where $\mathbf{n}$ is taken from the depth cube map face providing the smallest distance. s is the reaction strength that is to say the surface normal $\mathbf{n}$ multiplied with the smallest distances to the surface $d(\mathbf{v})$:

$$s = d(\mathbf{v})\,\frac{\mathbf{n}}{||\mathbf{n}||}\,. \qquad (2)$$

In order to remember the collision, the data-structure of the billboard is expanded by an additional value storing its recover time. In case of a collision the recover time is reset.

6.4 Shape Preservation

As the separate processing of individual vertices may lead to visually unpleasant distortions, a cloth model based on spring constraints [Pro95, FGL03, Zel07], is applied to preserve the overall shape of the grass clump. A network of structural and shear springs takes care of the billboard mesh. Whenever such a spring is compressed or stretched, which means the connected vertices diverge or converge, the resulting spring force translates the connected vertices.

Referring to Provot et al. [Pro95], a spring force $\mathbf{f} \in R^3$ between two billboard vertices $\mathbf{v}_1$ and $\mathbf{v}_2$ is defined as:

$$\mathbf{f} = k(||\mathbf{l}|| - l_0)\,\frac{\mathbf{l}}{||\mathbf{l}||}\,, \qquad (3)$$

where $\mathbf{l} = \mathbf{v}_1 - \mathbf{v}_2$ is the direction of the connection between both vertices. l_0 is the initial length of the spring and $k \in [0,1]$ is the stiffness of the spring. A stiffness of 1 results in a conservative spring in contrast to a value of 0 which has no effect. Each spring force directly affects the two connected vertices [FGL03, Zel07]:

$$\begin{aligned} \mathbf{v}_1 &\leftarrow \mathbf{v}_1 - r_1\,\Delta t\,\mathbf{f} \\ \mathbf{v}_2 &\leftarrow \mathbf{v}_2 + r_2\,\Delta t\,\mathbf{f}\,, \end{aligned} \qquad (4)$$

where r_1 is the responsiveness for vertex $\mathbf{v}_1$ and r_2 is the responsiveness for vertex $\mathbf{v}_2$ with $r_1 + r_2 = 1$. We added the responsiveness in order to distinguish between fixed ground vertices and movable vertices. As a fixed vertex

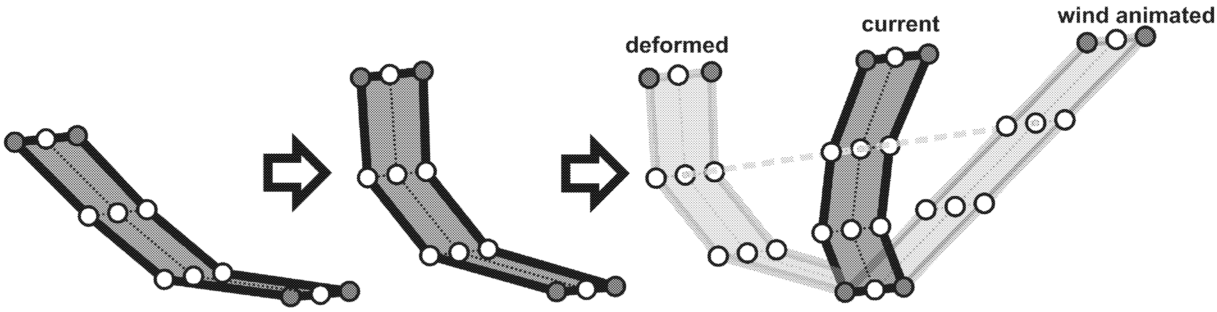

Figure 6: The interpolation between the vertices of the current mesh (deformed mesh) and the vertices solely affected by the wind animation results in a smooth recovering over time.

should not be moved, the responsiveness is set to zero whereas the other vertex then is completely responsive. If both vertices are not fixed they are equal responsive and thus $r_1 = r_2 = 0.5$.

As the relaxation of one spring affects the neighbouring springs as well, in general more iterations over all springs have to be applied to get a good result. In our case two iterations yield visually pleasant results due to the small number of vertices.

6.5 Recovering

The recovering is processed on each billboard that has some recover time left. Since the animation is a stateless process, solely based upon the position of the fixed ground vertices and the current time [Sou07], it is possible to compute the original shape defined by the wind without considering the current collision state. The linear interpolation between the deformed vertex and its original position, with respect to the recover time left, results in the current shape of the grass clump as shown in Figure 6:

$$\mathbf{v} \leftarrow (1-t^3)\mathbf{w} + t^3\mathbf{v}\,, \qquad (5)$$

where $t \in [0,1]$ is the recover time left, $\mathbf{w}$ is the vertex position obtained by the wind function and $\mathbf{v}$ is the current respectively last recovered vertex position.

Collision tests are required in case that there are still collision objects inside the AABB of the respective octree node. At every time without any collision, the recover time will be decreased. After the recover time has elapsed, the billboards will be handled again as simple quads. However, the recovering does not preserve the length of the billboards.

7 RENDERING

On the CPU level, grass tiles which previously have been streamed and others that have not been affected by neither collisions nor wind exist. The tiles run through separate render passes: Collided billboards are rendered using their current refined mesh whereas the unaffected ones are animated and rendered using their simple quad-representation. Furthermore, to overcome problems caused by too much render calls, only batches of visible tiles, which have not been culled by view or occlusion queries, are rendered.

7.1 Global Illumination

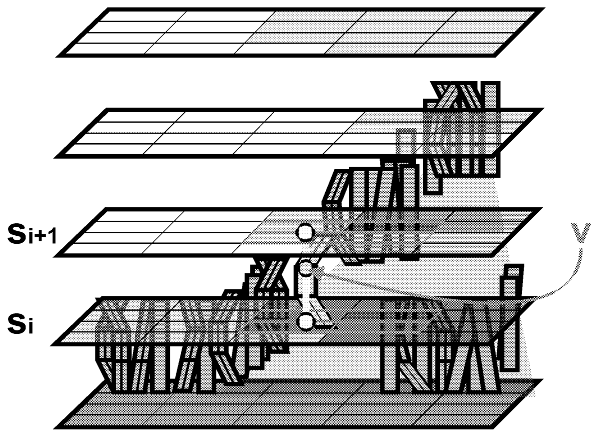

Figure 7: The irradiance for each vertex $\mathbf{v}$ of the billboard is interpolated within the two closest texture slices s_i and s_{i+1}.

Dynamic global illumination is achieved by pre-computing a volume, with each voxel storing ambient occlusion information for its location in the scene [CL07]. The whole volume is then stored as an 2D texture array to allow linear interpolation based on mip-mapping. In addition, a second volume which covers the same space provides pre-computed irradiance information for each point. The irradiance is determined by sampling an environment map by using the previously computed ambient occlusion information [PG04].

The texture coordinate for the volume texture can easily be obtained from the billboard's vertex positions in the geometry shader. Ambient occlusion and irradiance information is trilinear interpolated between adjacent texture slices, and the incident light is evaluated per vertex during the geometry shader process as illustrated in Figure 7. Finally, the pixel shader uses the texture index into the semi-transparent texture array to receive the decal color and transparency of the

Figure 8: The result of the collision handling in a dense field of grass.

grass clump. Multiplying this decal value with the incident two-sided light [KCS07] results in the final semi-transparent pixel color.

7.2 Alpha-To-Coverage

Since grass has a semi-transparent nature a feature of modern cards, so-called Alpha-to-Coverage, is used to blend the billboards without the necessity to perform expensive depth-sorting. The alpha value is used to determine the number of subpixels, that will be filled with the current pixel color. Then, blending between the subpixels is performed while resolving the multisample resolution to the final image resolution [Mye06].

8 RESULTS AND PERFORMANCE

Achieving a high performance is one of the major aims to real-time applications. All components concerning the grass layer are designed to reduce the workload of the CPU as much as possible. Thus, the simulation is almost completely shifted to the GPU. All the tests are performed on an AMD Athlon 64 3500+ 2.2 GHz processor including a GeForce 8800 GTX graphics card with 768 MB DDR3 memory. Figure 8 shows the response of the grass after the scene object has moved through the meadow. The scene, presented in Figure 2, is running at 40-80 frames per second by using DirectX 10 and fourfold multi sampling anti aliasing (4xMSAA). The grass layer contains 60000 grass billboards requiring 12 MByte of graphics memory. All invisible grass tiles are culled. The grass is pushed to the side or is stamped down on the line of movement. The object has left a clearly noticeable imprint on the grass. We analyzed the performance of the scene with the aid of the NVidia PerfHUD tool. In Figure 9 the number of colliding grass tiles (red boxes) respectively recovering grass tiles (green boxes) increases from top down. The lower left overlay displayed in each image shows the workload balancing of the programmable render pipeline stages: The unified streaming processors are utilized to work on pixels with about 50 to 60 percent (the blue bar) whereas the geometry shader unit of the pipeline is active by approximately ten percent (the green bar). The remaining workload is caused by frame buffer operations. Approximately 16 million pixels are processed within the fragment shader resulting in many read as well as write accesses to the frame buffer. Those are amplified by the Alpha-to-Coverage feature which in that case requires a multisample resolution that is four times higher than the image resolution. The diagrams located at the right hand side of each image in Figure 9 present the amount of time which is consumed within each GPU pass: Please note that the time spent within the recover process (R) and the collision pass (C) varies only by small amounts. In contrast, the more grass billboards are deformed the more time is spent rendering the collided and recovering grass tiles (RA). This performance loss is caused by the primitive generation as well as the rendering of the high number of primitives. Referring to the utilization graph and the time measurements the performance of the system depends on the number of assembled primitives which are passed through the rasterizer back-end. Thus, both the memory operations as well as the workload shifted to the fragment shader stage, are influenced by the number of colliding grass billboards. Consequently, it is necessary to set up a low recover time and to provide a low multi-sampling rate for the Alpha-to-Coverage process to preserve the overall performance. In contrast, the time spent within the collision handling depends mainly on the number of scene objects moving through the grass layer.

9 CONCLUSION AND FUTURE WORK

In the past thousands of billboards were successfully used to create an illusion of dense grass vegetation. In combination with wind animation nice visual results were achieved. But the visual perception was often compromised by lack of interactivity: Objects are moving through the grass without leaving a trace. Due to prior hardware constraints a visually pleasing collision reaction for a large area of grass was unachievable. The visual quality of dense vegetation and the good performance give a proof of the great suitability of our imple-

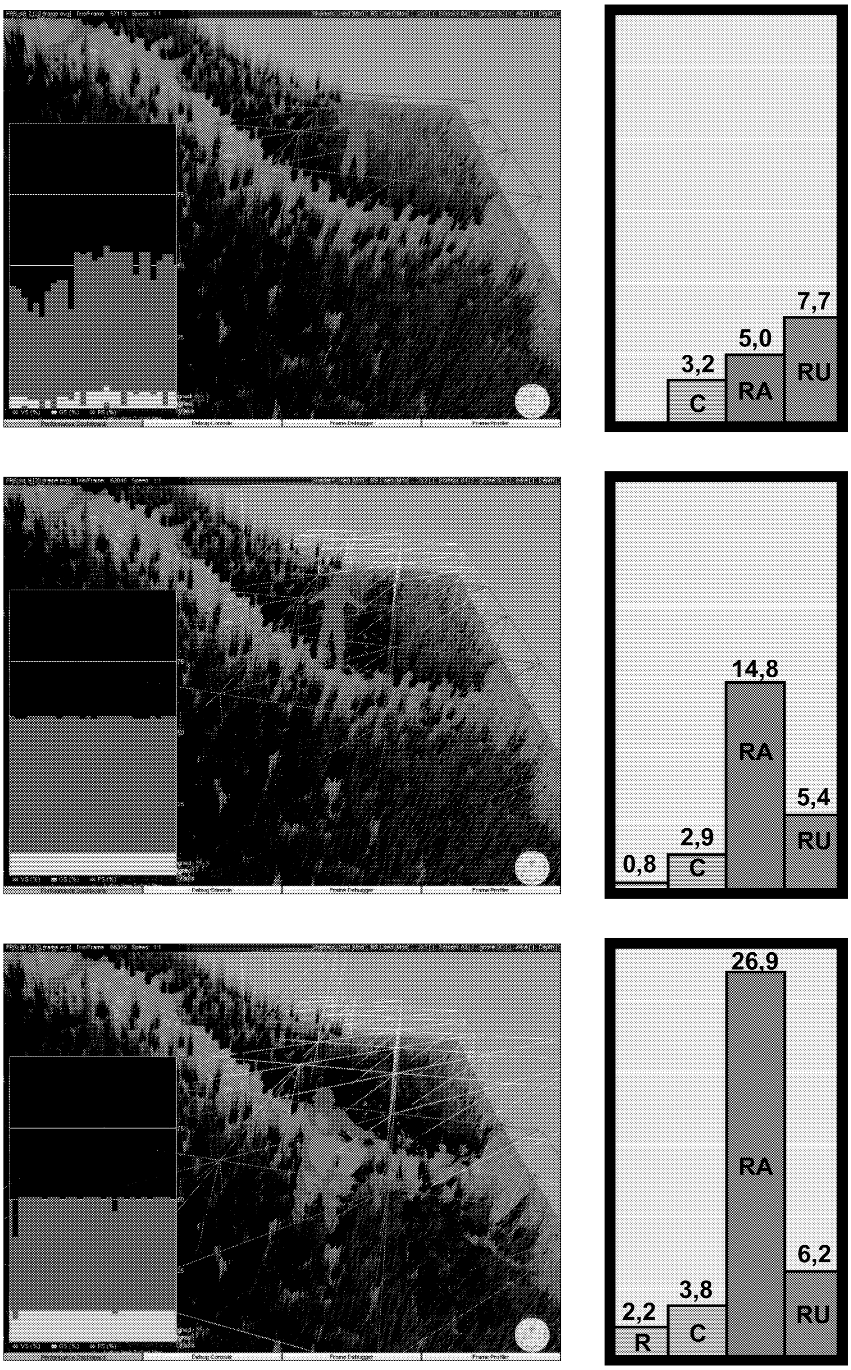

Figure 9: A scene which contains more and more deformed grass billboards. The time spent within each GPU pass is displayed in milliseconds on the right-hand side of the corresponding image. The measured passes are: The recovering pass (R), the pass performing the collision handling (C), the rendering of the possibly affected grass tiles (RA), and the rendering of the unaffected grass tiles (RU).

mentation strategies for large responsive grass layers in todays real-time applications.

The results are demonstrating that collision response works fine for regions where the flat structure of the grass billboards is hardly recognized. However, in areas where grass is planted sparsely, for example at the borders of the grass layer, due to the coarse mesh of the billboards the visual impression could be improved. Two different approaches might be promising when trying to solve this problem: On the one hand the collision handling for each billboard could be distributed over several streaming passes which allows the spring constraints to work on a higher subdivided mesh. On the other hand the displayed primitives could be assembled by a higher order interpolation during rendering.

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BIOGRAPHIES

JENS ORTHMANN has received a diploma in computer science in 2008 and is currently pursuing his PhD as a scholarship holder in the graduate college on *Heterosensor Architectures for Biochemical Analysis* at the University of Siegen, Germany. His research interests are real-time programming, fluid simulation and visualization.

CHRISTOF REZK-SALAMA has received a PhD in computer science from the University of Erlangen-Nuremberg. Currently he is an assistant professor at the University of Siegen and a lecturer at the Mediadesign University of Applied Sciences in Düsseldorf, Germany. His research interests are computer graphics, scientific visualization and game design.

ANDREAS KOLB is head of the Computer Graphics Group at the University of Siegen since 2003. His academic background is computer graphics and visualization. He received his PhD at the University of Erlangen-Nuremberg in 1995.

Towards Image Based Rendering in Computer Games

Christof Rezk-Salama
Mediadesign University
of Applied Sciences
40227 Düsseldorf, Germany
c.rezk-salama@mediadesign-fh.de

Severin Todt
Computer Graphics Group
University of Siegen
56076 Siegen, Germany
todt@fb12.uni-siegen.de

1 INTRODUCTION

This paper studies the problem of integrating image-based rendering techniques into state-of-the-art real-time computer games. We present a complete production pipeline for generation of light fields from arbitrary complex 3D content using commercial 3D modeling software commonly used in the gaming industry. We show how recent advances in light field rendering techniques can be used to composite light fields with dynamic scene content. The results demonstrate the potential of light fields as a valuable extension to polygonal rendering techniques by employing accurate silhouette reconstruction and correct per-pixel depth values for scene composition. Level of detail techniques are applied to light fields to optimize rendering performance. Dynamic light field rendering is implemented to account for animation, deformation and varying lighting conditions.

2 MOTIVATION

Today, the visual quality of a game title is one of the main keys to commercial success. Upcoming computer games unleash the power of state-of-the-art graphics hardware to achieve best visual results at maximum performance. Since Blinn and Newell introduced *Texture Mapping* in 1976 [3], image-based techniques are frequently employed to achieve sophisticated rendering results in real-time. Texture Mapping is heavily used today and has inspired a set of related image-based rendering techniques such as *Bump Mapping* [2], *Impostors* [13], *View-Dependent Texture Mapping* [7], *Relief Texture Mapping* [12], *Billboard Clouds* [8], *View-Dependent Displacement Mapping* [16] or *Omnidirectional Relief Impostors* [1], all of which contribute to the visual experience of today's computer games.

In contrast to *Relief Texture Mapping* and *View-Dependent Displacement Mapping*, light field rendering techniques (LFR) [11, 9] focus on the reconstruction of complex lighting and material attributes from a set of input images rather than the exact reconstruction of geometric details. LFR techniques as a powerful alternative to traditional polygonal graphics, however, have not yet been successfully integrated into current real-time games for various reasons. For LFR techniques to be successfully integrated into game engines they must at least provide:

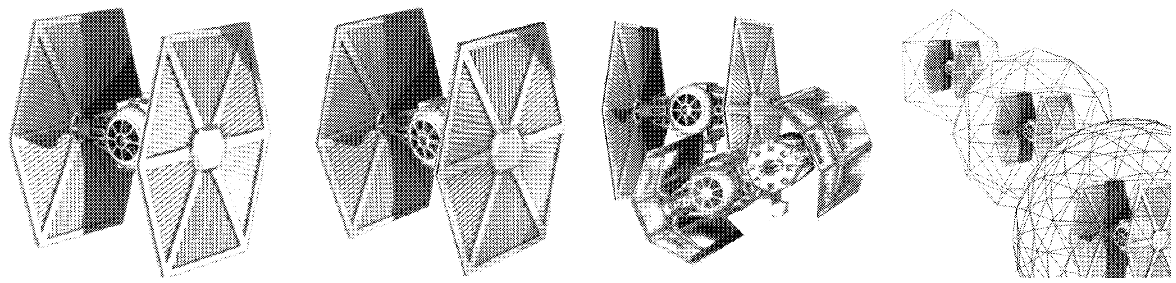
- High quality real-time rendering without visual artifacts
- Accurate compositing with dynamic scene content
- Level of detail (LOD) methods to adjust the render complexity
- Parameterized rendering algorithms to adjust the object to varying conditions
- Continuous 6 degrees of freedom (DOF) for free view point selection

In this paper we present a LFR technique compliant with these requirements and thus ready to be integrated into games. We show how LFR techniques emerging from recent progress on *Spherical Light Field Rendering* [15] can successfully be integrated into dynamic scenes. We employ a hierarchical light field parametrization to implement an LOD strategy to adjust rendering complexity according to the target performance (see Figure 1 d). We improve compositing capabilities for light fields by providing depth information for per-fragment depth culling techniques (see Figure 1 c). We present a dynamic LFR technique which allows lighting situations to be adjusted and to implement light field animations and -deformations (see Figure 6).

3 SPHERICAL LIGHT FIELDS

Spherical light fields provide a uniform sampling of the observation space by implementing a spherical parametrization on a bounding sphere around the observed object [5]. Recently a high-quality spherical light field implementation was presented by Todt et.al. [15] which facilitates the rendering of light fields without noticeable artifacts in real-time with 6 DOF. This technique is a basis for our LFR approach for use in computer games.

Representation The spherical parametrization is based on an icosahedron as a uniform approximation of the sphere. Originally providing 12 uniform distributed sample positions, parameterizations at higher resolutions are achieved by subsequently subdividing the icosahedron yielding 42, 162, 642 and more sample positions (see Figure 1, d). A



(a) (b) (c) (d)

Figure 1: a: Original Tie-Fighter model containing 16428 triangles rendered at 512×512 using Mental Ray in 39 sec.. b: Light field reconstructed from 42 samples sampled at 512×512 rendered at 78.3 fps. c: Composed Light Fields of Tie-Fighter and Tie-Bomber. d: Light field rendered at different LOD, with superimposed spherical approximations.

parabolic parametrization of the opposite hemisphere is associated and stored with each sample camera position (see Figure 2). In addition to the captured color intensities, per-pixel depth information is stored in each sample's alpha channel, providing interleaved *RGBz* data (see Figure 3). Using standard texture compression methods, a compression ratio of 4:1 is achieved. 2.7 MByte are sufficient to store a light field sampled from 42 sample positions at a resolution of 256×256 (10.4 MByte for 162 samples).

Generation Light fields are generated from synthetic objects by rendering the scene from the predefined spherical sample positions. Per-pixel depth is stored as the ratio of the camera sample position's distance to the object's surface point to the length of the ray secant according to Figure 2.

Rendering The smooth shaded spherical approximation is rendered for light field reconstruction, with the vertices being equivalent to the sample positions. For each triangle the parabolic *RGBz* texture images and the viewing matrices of the three cameras are bound to their associated vertices. For each triangle of the polygonal sphere, rasterization yields barycentric coordinates per-fragment. For each fragment a ray is cast into the scene. The raycast rendering algorithm described by Todt et.al. [15] is utilized to establish the intersection point with the surface of the captured object. Starting at the ray intersection with the object's bounding sphere, the ray is iteratively sampled at a fixed step size, as shown in Figure 4. For each sample position the assumption that the current ray position is the actual object intersection point is validated by projecting this position onto the camera sphere using the adjacent camera positions as center of projection. Depth values are obtained from the corresponding parabolic texture maps and local estimates are calculated for each camera. If one of the local estimates is equal to the ray position within a given tolerance, ray sampling is stopped. This means that we have found at least one camera that reliably observes an object intersection at exactly the ray position. For the final intersection point, the fragment color value is determined from the weighted sum of the light field

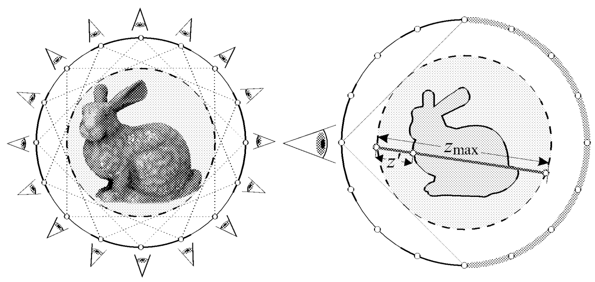


Figure 2: For light field generation the synthetic object is rendered from predefined sample positions. The depth value is obtained by dividing the bounding-object distance z' by the bounding sphere's secant length z_{max}.

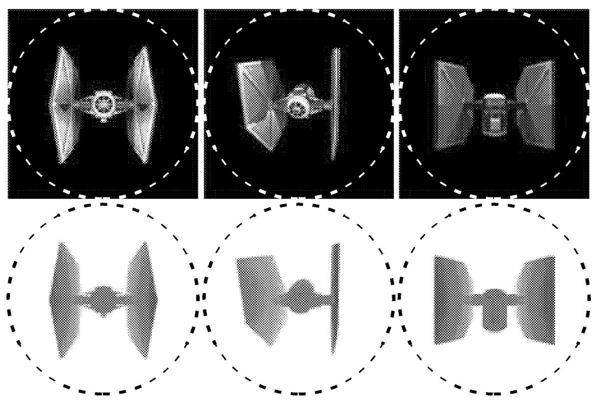


Figure 3: Three image samples taken for a spherical light field with 42 cameras. Each image represents a parabolic mapping of the hemisphere for color (top row) and depth (bottom row).

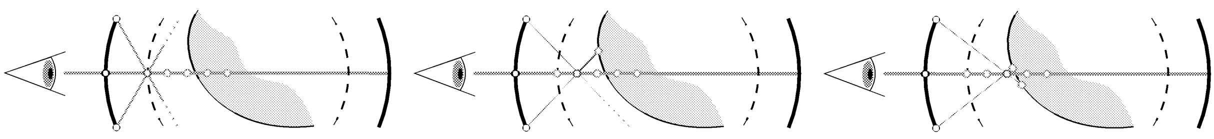


Figure 4: Ray casting approach employing per-pixel depth to establish ray-object intersection according.

samples. Per sample weights are determined based on distance of the local estimate to the current ray position.

Using the raycasting approach and per-pixel depth correction, light fields are rendered without noticeable ghosting artifacts yielding an accurate silhouette reconstruction (see Figure 1 b). In contrast to other image based rendering techniques commonly used in computer games, this spherical light field rendering approach is capable of reconstructing visual effects resulting from complex material attributes, e.g. anisotropic shading, or global illumination effects in real-time. Although techniques like *Impostors* [13], *Billboard Clouds* [8] or *Omnidirectional Relief Impostors* [1] are capable of reconstructing an object's visual appearance for a predefined position and viewing direction they do not provide any technique to reconstruct new virtual views containing the complete range of shading complexity represented in the source images in real-time. As shown by Andujar et.al. [1] geometric details are recoverable to a certain degree from relief impostors which than can be used to implement dynamic lighting and global illumination effects. This approach however comes at the price of high computational costs to implement sophisticated shading based on the geometric reconstruction. The spherical light field rendering performs independently of the scene complexity at real-time frame rates.

4 LIGHT FIELD RENDERING FOR GAMES

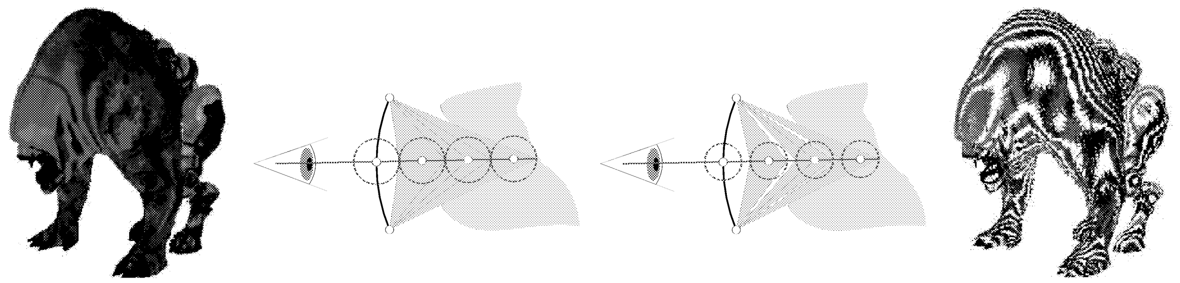
We adapted the spherical rendering approach and implemented optimized rendering strategies to sufficiently address the requirements of today's real-time render engines to successfully integrate light field rendering in real-time computer games. We take advantage of the spherical parameterization's hierarchical nature and the render algorithm's flexibility presented in Section 3 to implement an LOD strategy. We exploit per-pixel depth information used for depth correction of rays to improve light field compositing capabilities and we demonstrate a technique for dynamic LFR. For digital content creation we present a production pipeline including model generation and light field generation.

4.1 Light Field Rendering with LOD

Rendering techniques for complex scenes in computer games are mainly importance driven to optimize performance. Objects in focus are rendered at highest quality whereas distant objects are rendered at lower resolutions. The hierarchical arrangement of sample positions on the spherical approximation resulting from the subdivision of the initial icosahedron (see Section 3) makes the implementation of a discrete LOD strategy available for LFR. Additionally the rendering performance is continuously adapted to the quality needs for distant objects by adjusting the raycaster's step size and intersection evaluation tolerance .

The implemented LOD strategy straightly follows LOD strategies implemented for polygonal 3D models in interactive real-time applications. The LOD is adjusted by coarsening the polygonal approximation being rendered for light field reconstruction (see Section 3). Light fields rendered with a coarser LOD are reconstructed from fewer light field probes according to Chai et.al. [6] which reduces the amount of texture switches in the rendering process and thus reduces the graphics processing unit (GPU) workload (see Figure 1 d). The current LOD is determined in classical sense as a tradeoff of resolution vs. geometric quality. A maximum of 4 LODs is available assuming a highest resolution of the spherical approximation with 642 sample positions for the most detailed representation. The spherical sample positions are arranged such that all of the vertices of certain LOD are contained in the next finer LOD. No additional spherical approximations nor additional light field samples have to be generated and hosted for this LOD strategy. Coarser LODs are achieved by reducing the sample density in the geometric domain and the light field information in the image domain by reducing the amount of sample positions. Minor popping artifacts, however, can be observed during rendering on LOD switches resulting from image information that becomes recoverable with the higher amount of sample positions, e.g. concavities.

Rendering performance is further adapted to the object distance by adjusting the render settings for the raycasting algorithm to steer the reconstruction quality. As presented in Section 3 the precision of the raycaster is dependent on the chosen step size to sample the ray and the given tolerance at which the ray sampling is stopped. While the LOD strategy based on the reduction of sample positions implements a dis-



(a) (b) (c) (d)

Figure 5: a: Light field rendering of the DOOM Pinky character model. b: Showing recoverable area for tolerance chosen to be equal to half of the step size. c: Tolerance smaller than half of the step size result in unrecoverable areas. d: Unrecoverable areas appear as gaps in the light field rendering if tolerance is chosen too small with respect to the step size.

crete LOD strategy the render settings can be adjusted continuously with the object distance. A performance gain is achieved by increasing the raycaster's step size. However, discontinuity artifacts are likely to appear due to the incorrect reconstruction of object surface points used to sample the light field probes of the ray's adjacent cameras. Small geometric details are not recoverable with step sizes chosen too large. Notice that the step size is correlated with the chosen tolerance. While the step size can be chosen without theoretical constraints, the tolerance is to be chosen according to the step size. Choosing the tolerance to be less than half of the step size will result in visual discontinuities as local estimates will not be reconstructable from adjacent cameras for all ray positions. With rising angular distance of the adjacent camera with respect to the current ray position the camera's reconstructed local estimate will most likely fail the tolerance test. Tolerance values chosen to be smaller than half of the step size appear as equidistant isosurfaces with a distance equal to the step size and with empty space gaps of size $StepSize - 2 \times Tolerance$ in the light field rendering (see Figure 5). The combination of both LOD rendering approaches results in a gain of rendering performance and rendering flexibility which allows multiple light fields to be displayed simultaneously by rendering instances of the same light field or different light field objects. Instancing shows higher performance compared to rendering multiple separate light field objects. Rendering multiple distinct light fields results in numbers of texture swaps on the GPU leading to lower rendering performance, whereas with instancing a single light field renders without texture swaps.

4.2 Light Field Compositing

In [15] ray-object intersections are established per-fragment for accurate silhouette reconstruction and to reduce ghosting artifacts. We use the barycentric fragment coordinates in combination with the ray-object intersection point to determine per-fragment depth values during light field reconstruction at no extra costs in order to take advantage of *OpenGL's z-Buffer* functionality.

The ray-object intersection point yields relative distances to the three adjacent sample positions. Based on the barycentric weights the fragment's position in world coordinates is established according to the known sample positions. By projecting the reconstructed surface point into the current view, per fragment depth values are determined for the surface point according to the current viewing transformation and projection matrices.

Light field renditions can be composed with arbitrary complex polygonal scenes by applying the precise silhouette reconstruction in combination with the per-fragment depth values. The compositing capabilities also allow multiple occluding light fields to be accurately displayed. Inter-object occlusions for polygonal objects and light fields are properly handled for dynamic and static scenes (see Figure 1 c).

4.3 Parameterized Light Field Rendering

The low memory footprint of the spherical light field representation in combination with the performance of the LOD rendering algorithm provide the tools for dynamic LFR. Various light field states can be represented by generating a set of light field samples for individual sample positions. The efficient light field representation facilitates to hold multiple light field samples for individual sample positions on the GPU ready to be rendered in real-time. Using the *nVIDIA GeForce 8800 GTX* providing 768 MB of onboard GPU memory, up to 280 distinct light field samples can be stored for each sample position of a single light field acquired at a resolution of 256×256 from 42 sample positions (990 distinct samples for 12 sample positions). The rendering process is steered by adjustable parameters in real-time to reconstruct a light field object with varying state. For parameterized rendering the light field samples corresponding to the current state are used to reconstruct the

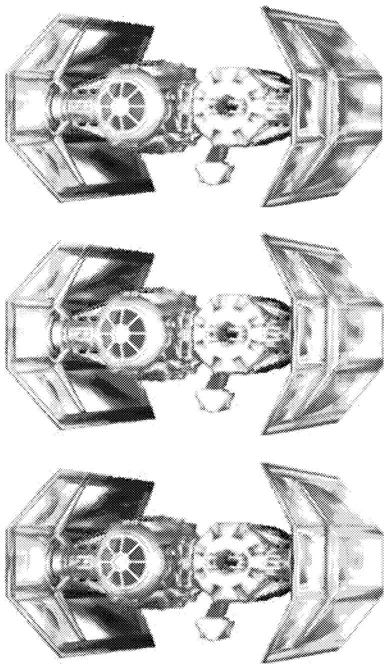


Figure 6: Tie-Bomber light field rendered with interchangeable dominant lighting direction (red light source chosen for visualization purposes).

light field. This techniques opens up many possibilities for various applications, e.g.:

Deformation Dynamic deformable objects must show deformations in case of collision. Preparing light field samples for different deformation states provides capabilities to adjust the visual appearance according to the collision. Note that for the changes to the light field objects, we need to store additional images only for those cameras, which actually observe the applied modification. Hence, for minor changes to the object only a small subset of the camera images need to be stored in addition.

Lighting Conditions The visual appearance of the light field object must adjust to changing lighting conditions. With parameterized rendering the light field state can be adjusted for e.g. changing environments or dominant lighting directions (see Figure 6).

Changing lighting conditions are reconstructed from a set of pre-acquired light field samples captured for varying lighting conditions. For flexible and continuous reconstruction of varying dominant lighting directions we acquire light field samples for a discrete set of predefined light directions. The lighting direction is disretized based on the spherical approximation also taken for acquisition due to its uniform characteristic. For each light field sample position a sample is acquired for each discrete light direction,

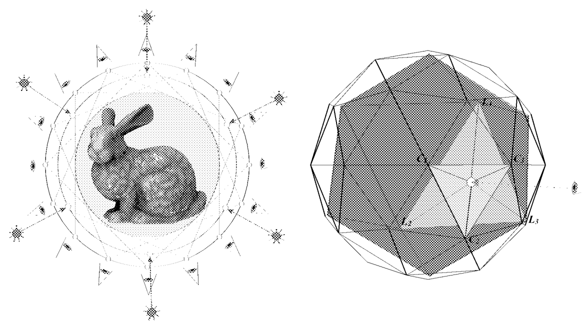


Figure 7: Left:Lighting directions are discretized by a spherical approximation (orange) similar to the approximation used in the spherical camera setup. Right: Barycentric weights are established based on the spherical proxies used for lighting and light field acquisition.

defined by the spherical light discretization proxy (see Figure 7, left). The resolution of the spherical proxy used for lighting can be chosen freely. It does not correlate with the camera resolution chosen for light field acquisition.

For rendering the light field the spherical light proxy is applied to identify the light directions (L_1, L_2, L_3) from the set of discrete light directions that contribute to the current viewing direction and thus chose the corresponding set of input images for light field reconstruction (see Figure 7, right). According to the intersection point of the current view direction with the spherical light proxy, barycentric blending weights are determined. The light field is then rendered using the light field samples acquired for the discrete incoming light directions as input images. Rendering is performed in three distinct rendering passes according to (L_1, L_2, L_3). The render results, being rendered to an off-screen render target are blended in a final render pass using the barycentric weights from the light proxy intersection as blending weights.

This interpolation allows arbitrary lighting directions to be interpolated continuously within the rendering process. Other applications may use this approach for blending light fields acquired for a discrete set of environment maps or other complex lighting situations. Although the total amount of input images is factored by the amount of discrete lighting directions, rendering is still performed at real-time frame rates of 47.5s fps for a light field sampled from 42 positions for 12 discrete light directions at a resolution of 512×512.

Animation Animation sequences of single characters have proven to be well suited for storytelling. Interactivity is added if dynamic light field rendering is used instead of offline rendered video footage. Animated light field rendering allows the user to adjust

Figure 8: Animated light field rendering of the Ray character model, showing an extract of six animation frames.

viewing direction and position freely while the animation is played. Light field animations are rendered at slightly lower (-10%) frame rates compared to static light field rendering. The light field animation shown in Figure 8 was rendered at real-time frame rates but limited by the target video frame rate of 24 fps.

Light field animations are rendered sequently as defined by the sequence of input images. Theoretically there is no limitation in the length of the animation, as streaming technologies are applicable for light field animation rendering as well. The animation presented in Figure 8 however was generated as a static setup of light field samples, being uploaded on light field instantiation. Here the maximum length of the light field animation is limited by the render target's total GPU memory size.

4.4 Light Field Production

For a successful integration of light fields into a game title game developers are in need of a sophisticated production pipeline to generate light fields from content created by commercial 3D modeling software commonly used in the computer game industry, e.g *Autodesk Maya*. Currently none of the available 3D modeling tools directly supports light field exports of any kind. Using our *Maya* light field generation plug-in, arbitrary complex 3D content can be converted to light field data sets. Any rendering engine available for *Maya* can be used to generate light field samples from 3D content to exhaust *Maya's* complex shading and rendering capabilities. Current versions of the plugin-in support *Maya Software Renderer* and *Mental Ray*. The plug-in allows single light fields to be created automatically or a set of light fields from a predefined animation sequence. In the case of animation, individual light fields are generated for each time step and being merged to a light field collection data set to be used as a light field sequence.

A light field is exported by automatically rendering the scene from pre-defined sample camera positions given by the spherical approximation. The rendering is performed in two steps. The RGB color values are rendered in a high-quality rendering pass employing all of the image quality features defined by the artist. Image improvement techniques available with *Maya's* renderers, however, also effect per-pixel depth information stored with the rendering result. Depth information is extracted in a second render pass, rendered at low quality using *Maya's* software renderer yielding unfiltered per-pixel depth values.

A separate rendering process is employed to convert the complete set of *Maya* samples to the light field representation described in Section 3. For each camera position the rendered high-quality images in combination with the depth information are used to reconstruct a view-dependent depth relief. This is achieved by constructing a highly tessellated polygonal mesh representing the near plane of the viewing frustum of the individual camera. Each vertex is now displaced according to its correct depth value. This geometry is used for light field generation by projecting the vertices to the hemisphere opposing to the current camera position. The projected color and depth information is stored as a parabolic map for each camera.

5 DISCUSSION AND RESULTS

Comparable light field rendering techniques presented in the past provide 6 DOF for view synthesis at real-time frame rates but do not meet all of the demands of computer games. *Spherical Light Fields* presented by Ihm [10] employ a comparable parametrization at a significantly higher sample count yielding much larger data sets. Light fields are rendered at high quality showing only minor ghosting artifacts. The data size and high amount of samples considered in the light field reconstruction, however, reduces flexibility and aggravates rendering performance. *Unstructured Lumigraph Rendering* [4] and *Free Form Light Fields* [14] implement a free-form parametrization that provides 6 DOF at varying sampler counts. Both techniques apply a depth correction of rays for high-quality light field rendering but still lack accurate silhouette reconstruction and correct per-fragment depth values necessary for scene composition. For *Unstructured Lumigraph Rendering* a geometric approximation is used for depth correction which has to be generated separately, stored and processed with the light field data. No geometric approximation is stored for *Free Form Light Fields*. Instead, a polygonal mesh is generated from the sample positions freely distributed in space around the captured object. For light field rendering the generated mesh is subsequently subdivided to yield a fine geometric approximation based on depth values stored with individual samples. The time consuming subdivision process affects rendering performance to a high degree. None of these techniques neither provide a complete production pipeline for automated light field generation from sophisticated 3D scene content nor do they provide parameterizable light field rendering or LOD techniques.

In this paper we demonstrated the usability of our spherical LFR technique for real-time games. Our technique provides a valuable extension to current rendering techniques used in real-time gaming applications. We have shown that spherical light fields provide a high-quality alternative to represent complex models in dynamic scenes. The parameterized rendering of light fields yields the key to dynamic light field content allowing the appearance of the light field to be controlled in real-time. Our rendering technique is optimized for parallel rendering of multiple light fields and the composition of light fields with dynamic scenes. Best rendering results, however, are achieved for scenes including a single high-quality light field of a detailed 3D model included in a polygonal environment to enhance visual quality. With LOD rendering light fields sampled at a resolution of 256×256 are rendered at a screen size of 512×512 with frame rates up to 85.56 fps for a LOD corresponding to 12 samples. (LOD(42): 79.1 fps, LOD(162): 60.4 fps). Multiple (10) instances of the same light field are rendered at up to 69.58 fps for an LOD(12) and 43.25 fps for an LOD(42).

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BIOGRAPHIES

CHRISTOF REZK-SALAMA has studied computer science at the University of Erlangen-Nuremberg. In 2002 he received a PhD at the Computer Graphics Group in Erlangen as a scholarship holder at the graduate college "3D Image Analysis and Synthesis". After that he was working as assistant professor at the Computer Graphics Group at the University of Siegen, Germany and gained his postdoctoral lecture qualification (habilitation) in computer science and computer graphics. Since October 2009 he is working for the Mediadesign University of Applied Sciences in Düsseldorf, Germany. The results of his research have been presented at international conferences, including SIGGRAPH, IEEE Visualization, Eurographics, MICCAI and Graphics Hardware.

SEVERIN TODT has earned degrees in media information sciences and computer science at the University of Applied Sciences Wedel and a Diploma degree in computer science at the University of Siegen. He is regularly teaching courses and seminars on computer graphics, 3D modeling, character animation and graphics programming. He has received a Ph.D. in computer science at the Computer Graphics Group at the University of Siegen. The title of his dissertation was "Real-Time Acquisition and Rendering of High-Quality Spherical Light Fields". His research interests include image-based rendering technologies, virtual reality applications and human computer interaction.

ONLINE GAMING

The Profi League Continues – An Online Gaming Community for Professional Players

Michael Ehret
Nottingham Trent University
Michael@michael-ehret.com

Tobias Fritsch
Freie Universität Berlin
T.Fritsch@gmx.net

Benjamin Voigt
Freie Universität Berlin
Benjamin.Voigt@gmail.com

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1. Abstract

With the growing influence of online communities, their members became a part of the scientific analysis over the last years. Especially in the entertainment section, like online gaming, the virtual environment that is offered by the online communities is closely related to the content of the games themselves.

Active participation in these communities is a key factor driving the attractiveness of online communities, such as higher contribution rates or good arguments for topic related discussions. One striking phenomenon is the existence of professional users, who have been noticed to drive attractiveness in online-gaming. Like in real sports, professional e-gamers are gaining financial profits and star-status.

In this paper we define professionalism and evaluate its influence on online gaming communities in an experimental environment. We created an online community for the massive multiplayer online game World of Warcraft. The webpage contains information about one aspect of the game: the "Player vs. Player" (describes the part of the game where players can fight against each other and not against the AI) game content. The online community contains a public and a restricted area, which is only accessible for the professional users.

The main findings of the experiment are a higher activity of the professional players, higher value adds for the online community and a more intense discussion in the restricted area. Other results are counter-intuitive on the other hand. The data does not support the hypotheses that professional users have a higher contact rate with others and that they will prefer the "2k+ lobby" over the remaining forum. This implies that professionals tend rather link hitherto unconnected parts of the network by striving to strengthen their social capital.

The remaining paper structures as following: section 2 features the background information about the online gaming communities and the definition of professionalism in computer gaming. Section 3 describes the approach, with a focus on the research structure, the relevant influence factors and the hypotheses. Section 4 covers the experimental measurement and the design of the experiment. Afterwards section 5 includes a statistical analysis of the hypothesis and a description of the results. In section 6 these results are discussed, finally section 7 concludes the main findings and gives an outlook about further research potential.

2. Background - Professional Users and their Impact on Online Communities

Since the accelerated diffusion of internet use in the 1990's marketing professionals have sought to exploit the potential of digital customer relationships (e.g. Hagel 1999, Kotler/ Achrol 1999, Kozinets 2002). In that regard virtual communities provide companies with the potential for efficient, direct feedback, the support of positive electronic word of mouth and the maintenance of co-creation relationships with their customers. Thus, attracting and committing participants to online communities is a necessary condition for their profitable use (Bart 2000/ Koh et al. 2007).

However, companies report mixed evidence with regard to the use of online communication and virtual social networks (Economist 2007, Koh et al. 2007, Ren et al. 2007). One issue for many online communities and social network sites seems to reside on the maintenance of participation of users and the stimulation of lively interaction between users (Ren et al. 2007). Thus, marketing researchers have started to investigate tools and concepts that attract participation in online communities.

Several studies document the role of so-called lead users or community leaders (Hippel 1988) in stimulating community interaction and providing insights for community operators (Ren et al. 2007). Thus, an improved understanding of the motivations and characteristics of community leaders is likely to expand the understanding of community dynamics and provide insights into the management of virtual communities. Social Capital theory has identified a specific role of pioneering users within communities: proficient networkers act as knowledge entrepreneurs by bridging structural holes within a network: They gain knowledge in one part of the network in order to strengthen their position in hitherto unconnected areas. (Burt 1992, Van Den Bulte and Wuyts 2007). Professional users can be considered as such entrepreneurs who are likely to invest time, expertise and knowledge in creating maintaining relationship within the community, while providing suppliers with ideas and acting as value-co-creators (Van Den Bulte and Wuyts 2007, p. 33, Kirzner 1979).

Due to their expert knowledge, the lead user potential (and early insights) can be leveraged by the producer to generate innovations, which (in the long run) will be beneficial for all users. Online

communities in general act as platforms for discussions to identify those needs.
One interesting fact of professional players is that they invest a significant share of their time in order to gain financial returns and/ or social capital. Therefore, professional players show decisive characteristics of lead-users: They act in many instances as sources of new ideas and early feedback providers for the gaming industry. Due to the fact that the developer can change the rules of the online game, two significant differences between the definitions exist, as will be discussed in the next section. As active seekers of gaming expertise they are a vital element in the diffusion process of games to more consumptive-behaving, passive gamers. Professional players are characterized by two further aspects:
"*3) Professional players aim to receive an information advantage over the other users in order to gain a competitive advantage in the online game, and*
4) Professional players are dedicated to show their gaming skills in order to receive social capital."
Figure 1 concludes the four traits of professional players in a diagram.

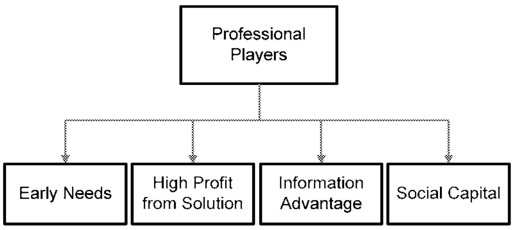


Figure 1: Illustration of the professional player traits

Both characteristics are differences between the professional players and the common lead user definition. This paper investigates the effect of professionalism within online-gaming communities with an experimental setting. Although gaming communities are a separate class of online communities in the classification of Lechner and Hummel (2002), yet they lack the required in-depth analysis. Therefore this paper aims to create a valid experimental environment to document the influence of professional players on these communities.

3. Approach – Measuring the Influence of Professional Players in an Experimental Environment

The growing importance of the online gaming communities is documented both in their increase in numbers and the game-features of the current video games. The aspect of multiplayer options as well as a community to support the necessary game information documents the current game development trend. According to Gamespot.com, nearly all recent top-selling games feature both at least a variant of multiplayer support as well as a user community for feedback, patches and game information. Yet these communities need to be evaluated, by understanding the influence factors for a successful online gaming community, it is possible to gain an advantage over competitors.
One possible influence factor is the existence of professional players. This chapter describes the research structure of the experiment, pinpoints the main influence factors to consider and features the hypotheses about their influence.

3.1 Research Structure

The analysis of a possible influence from professional players on online gaming communities uses an experimental environment. An existing top-selling online game was chosen to be representative for the current online gaming scene. The alternative would be programming a game for the experiment, although the (online-) game design has become to complex over the last decade that current top selling games require a huge amount of capital and time. Examples for current programming efforts are Grand Theft Auto 4 and Everquest 2, both cost more than 100 million Dollars, mainly due to the massive amount of game content, the high graphical performance and the complexity of the games. Therefore the decision felt on an existing online game: World of Warcraft, which is currently the number 1 massive multiplayer online game.

Online Community Decision: In order to offer the community of players a motivation to join the online community, its design needed to be up-to-date and the content needs to focus on a particular aspect of the game. In our case, the new online community (Gamersid.eu) focuses on the player-vs-player aspect of World of Warcraft. The reason for this specialization relies on two main aspects. First, the player-vs-player community in World of Warcraft offers the necessary potential for new communities, since the strategies are changing frequently and players discuss the latest game changes. These changes influence the distribution of power amongst them, since the game itself features different classes with unique abilities, which makes balancing them for player-vs-player combat difficult. The other main reason for choosing the player-vs-player section in World of Warcraft is the ladder system that the game uses.

Quantification of "Professionalism" in World of Warcraft: The internal ladder is based on an ELO-system, which is originally used for the world-ranking in chess. The ELO rating system is a method for calculating the relative skill levels of players in two-player games such as chess and Go.
By addressing a representative number for the "skill" of a player, World of Warcraft offers a method to quantify the sub-group of professional players.
The professional players in World of Warcraft do not only play better compared to others, they also share the described traits, such as early needs, information advantage and a need for social capital. To quantify professionalism, we define the "professional player" as a user in World of

Warcraft with 2000 or more rating, whereas the average player has around 1500-1700 rating. These numbers are based on the experience from previous pvp-seasons (season 1-4) and from the personal rating system of Blizzard Entertainment (the producer of World of Warcraft). The game uses around 2000 rating as the requirement for the most valuable player-vs-player equipment – the idea behind this requirement is that only a few, very skilled players shall reach this level and obtain this equipment as a reward (which is similar to the earlier definition of professional players).

The Online Community: The experimental environment is an online gaming platform, mainly focussing on the pvp-aspect of WoW (World of Warcraft). Figure 2 illustrates the design and shows an article about the current "build of the week" – a team setup for WoW.

The online gaming community was launched at www.gamersid.eu – the decision for the target group fell on the Wow-server "Theradras" in the server-cluster "Raserei". Both the server and the Cluster are German, therefore the language of the online community is chosen appropriately. Theradras was an optimal decision, since it is a full-pvp server (which usually attracts many players, who favour this kind of play-style). Another aspect is the personal contact to professional players from this realm, making it easier to find appropriate community members.

By featuring more than just a forum, the online community represents a comparable online environment to other professional online gaming communities. The sites' content ranges from informational articles, such as the build of the week up to media impressions (like current videos from pvp) and of course a forum, which will be the main source of information for our experiment.

In order to participate in the forum (which is also designed in German for a higher adoption rate amongst participations) the user needs to create an account. The advantage of user accounts is that they are individualized and each activity within the forum can be traced directly. This allows to gather data like number of logins, number of posts, activity, persona messages to other members, each user also has an individual link to attract new members.

The forum itself is divided into two parts – one that is available for all subscribers. It contains information about the so called "arena", a part of the WoW player-vs-player mechanisms, where opponents can face each other under standardized conditions (this uses the ELO system). Also a part for Battlegrounds, which are basically open areas for player-vs-player interaction without restrictions and a section for Looking for Team(member)s, where players could look for others to form new teams.

Additionally an exclusive area was created, called the "2k+ lobby", an area where only a few users have access to. These users needed to proof that their characters have achieved at least a rating of 2000+ within the game, which would qualify them as "professionals" in terms of pvp-skills for WoW. The purpose of this area is to evaluate the dynamic of a purely professional player driven online community. Mainly giving them the opportunity to look for equally skilled team-mates or make up arrangements for game sessions.

The Online Gaming Community Approach: In order to measure the influence of professional players within a gaming online community, an experimental approach is chosen. This is the first part of the overall research and this paper will thus focus on its description and analysis.

The first part of the experiment evaluates the difference between the forum section of the online community and the 2k+ lobby. The treatment for this experimental setting implies that one of the community areas observes the whole sample (all users of the online community). In the other section only a very limited sub-sample of professional players is observed in their interaction. Due to the technical design of the online community, each user-activity can be traced and stored in a database to be statistically analyzed afterwards.

This approach is a quantification of the player's behaviour within a given experimental setting. One important aspect is the motivation of professional players' to participate. The separation into the two sections (normal and "2k+ lobby") offers a way to measure their perception of the importance of information exchange vs. social capital. If the "2k+ lobby" is used more frequently, one explanation for it would be a strong favour of information exchange over social capital from others by the professional players.

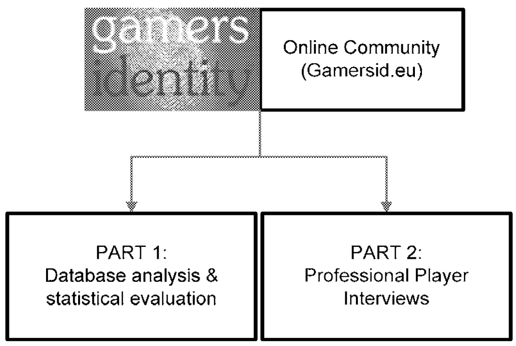


Figure 3: Illustration of the two parts of the professional player analysis in online gaming communities.

Leading research-questions for this setting are: "To which extend do professional players differ in their behavior compared to the other users?" and "Is there a statistical significant difference in the usage of the normal and the 2k+ lobby area?"

Figure 3 illustrates the two disjunctive approaches, which utilize the gamersid.eu platform.

3.2 Hypotheses

The hypotheses of the experiment evolve around the leading question: Is there an influence in terms of a "value add" from professional players for online gaming communities. If an influence exists, which examples illustrate it?

Hypothesis A1: Professional Players have a significant value add for online gaming communities.

This hypothesis describes the proposition that an influence exists. It can be statistically evaluated through the overall number of logins, the overall number of new members acquired and the overall number of guides provided for the community. Also non-quantitative variables, such as the quality of posts or the influence on other community members would underline the hypothesis. The described variables imply that professional users generate a certain core competence, which can be an advantage compared to other online communities. Especially in terms of information exchange, this core competence is inimitable, since the professional players' superior insight in game mechanics acts as the source of the valuable information for the rest of the community.

Hypothesis A2: Professional Players in the experiment show a higher activity on average in the online community.

This hypothesis describes a higher activity in terms of quantifiable variables, such as the number of posts and logins. If the hypothesis is true, on average the number of posts of the sub-sample "professional players" in the public area would exceed the number of posts of the casual players. It would therefore underline that professional users contribute more towards the user generated content compared to others. Different users will have different sign-up dates; in order to standardize an overall activity the used values to determine "activity" are posts per day and logins per day.

Another variable is the number of users with 0 posts in this context, these users would utilize the forum as a source of information without providing own content. This behaviour is similar to the leeching behaviour in file sharing communities.

Hypothesis A3: Professional Players have a higher contact rate with other members of the community.

This hypothesis is based on the personal message system of the community. Non-public messages (private messages) can be send through an internal message system of the community site. Without scanning the content of these mails, the number of messages received and sent by a user indicates his/her communication activity. It is measured in number of received mails per day and number of send mails per day. The hypothesis implies that professional players have a higher number compared to the other members.

Hypothesis A4: Professional Players show a higher activity in the "2k+ lobby", since their need for information exchange prevails over their need for social capital.

This hypothesis implies that the professional players will be more active in the closed section of the webpage (the 2k+ lobby). Reasons for this implication are a) the motivation to be an "elite", thus having the opportunity to discuss in an exclusive environment. Furthermore b) the knowledge that every other member of this section also has an in-depth game knowledge and therefore can provide much more valuable contribution to discussions. The activity is based on a comparison between the average posts per day of professional players in the 2k+ lobby and their average posts per day in the normal forum. In order to support the hypothesis, the number of posts in the closed forum must exceed the number of posts in the normal forum.

4. Measurement and Instruments – Ensuring the Validity of the Results

This chapter describes the measurement methodology of the approach. In order to ensure a high validity, the measurement instruments are chosen carefully. The first section contains information about the statistical measurement of the online community. This includes a description of the database, the number of datasets and the data quality. The second section describes the design of the interview, illustrates the sample of the professional players and the question inventory as well as the methodology to ensure a high validity of the interview results.

4.1 Experimental Measurement in the Online Community – A statistical database-related Approach

The online community offers a virtual environment for an experimental approach for evaluation of online gaming communities. After the launch, the URL was announced in the official WoW-Realmforum, a particular sub-forum of the WOW-community from Theradras. The overall time span for data gathering was two weeks (from release to the stop of gathering).

This short time span was chosen, since a possible influence of professional players would be best documented in a) a completely new environment and b) during the building phase of an online community. The observation focussed on the forum section of the online community, because whoever wanted to participate or read the forum needed to register first.

Based on the content management system of the online platform (gamersid.eu), the webpage has a continuous connection to the underlying database. This database receives information about all user activities (such as posts, logins, views, private messages) and stores them with timestamps.

Overall 116 participants signed up during the two weeks. Figure 4 illustrates the distribution of subscriptions during this period, beginning with a relative high number of 14 subscriptions per day; the curve shows a strong diminishing after the first week. During word of mouth and intense discussions more members (compared to the end of week1) subscribed afterwards in week 2. The average membership time of the overall sample was 7.8 days (out of 14).

The quantification of professionalism can be achieved through various methods. For this experiment we choose to stick to the ELO score, since it accurately reflects the success of a player in the game and gives a comparable number.

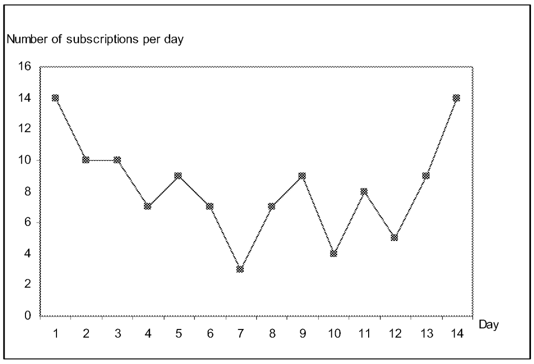


Figure 4: Timegraph: Number of subscriptions per day during the experiment period

Each of the professional players needed to contact us directly in order to proof his success in the game (an ELO score of 2000+) and to receive the access to the 2k+ lobby area. Within the first three days, most of the requests for professional status were received. Overall 33 players applied for the 2k+ lobby, 19 of them could proof the necessary score of 2000+. Hence the 19 out of 116 participants (16.4%) formed the sample group of professional players.

The posts in the forum are differentiated between posts in the "ordinary" forum sections, which include the arena-pvp, battleground-pvp and looking for member-pvp section, and the posts in the lobby section. Overall 315 posts are made in the normal section and 18 posts in the lobby section of the forum. Both the overall posts in the forum and the daily posts show a tendency towards the normal section.

The sample for the ordinary section are all registered users with 94,5% of the total posts in this section, meanwhile only 5,5% of the total posts are made in the 2k+lobby. Compared to a the difference in daily posts per person, the ordinary section received 0.82 posts per day on average, meanwhile the sample of professional players who are appropriate to post in the lobby section only had 0,44 posts in this section per subscription day per user.

The login rate also greatly differs between the players. Overall 1486 logins in the forum section are counted, the minimum number of logins is 1 in a few cases, whereas the maximum number of login during the test period is 26, which is nearly twice a day. On average the users logged in 12.8 times during their average 7.8 days of membership.

The private message function was used in different intense also, some members were frequently asking questions with private messages, meanwhile others did not use the system at all. Overall 63 private messages are sent during the two weeks, many users did not send a single message, and the maximum messages from a single user during this period were 12. On average each user sent 0.5 private messages during the two weeks.

Due to the registration, each user received an individual ID in the database, which made the allocation of all actions distinct. In terms of scalability, the approach offers a great flexibility, with a high-performing database; the content management system is also capable of supporting much larger forums (like 1000+ users).

5. Analysis– Evaluating the Results of the Experiment

This section contains the analysis of the hypotheses. The first part focuses on the hypotheses about the influence of professional players in the online gaming community, meanwhile the second section contains the analysis of the interviews. Finally the most important findings are highlighted, since not all of the hypotheses turned out to be true and thus this chapter also contains counter-intuitive results.

5.1 Experimental Environment – The Online Gaming Community

The different hypotheses for the professional player influence on the online gaming community depend on the database of the CMS system. Most of the hypotheses require an ANOVA, differentiating the complete sample into two sub-samples: a) the casual players and b) the professional players. For each hypothesis a null hypothesis with the opposite statement is created and used for the ANOVA, if the result indicates a statistically significant enough value, the null hypothesis can be rejected and the original hypothesis holds true. The used error probability for the following hypotheses is α=5%. The data is normally distributed, tested with the Jaque-Bera test. The critical value for the ANOVA is Fcrit = F (10,100) = 1.93, this will be used for all of the following hypotheses.

Hypothesis A1: Professional players have a significant value add for online gaming communities.

The main hypothesis for the professional player influence on online gaming communities indicates that they have a "value add" for the community. This value add can be measured by a higher participation rate of them, a higher contribution of content (in form of game guides) and a higher number of members that join the community because of the professional players presence. The higher participation rate holds true, as shown in hypothesis A2, because the professional players have more logins per day and a higher number of posts per day on average compared to the remaining sample.

The higher contribution of content can be illustrated at the overall number of guides written. These guides can be submitted by players and either posted in the forum or directly sent per mail. Their purpose is to give an overview about a topic, such as a team-setup and its fundamental tactics. Overall 5 guides are provided by players, all five of them were submitted by professional players, which further supports their higher value add for the community.

Finally the number of new members attracted by the users could be measured by the CMS system, because every user has his/her own link to attract new members. No further benefits were given for the attraction, except that community members received the information that their number of attracted members is measured.

Overall the majority of the new members did not use the provided links, only 22 of 116 members were subscribing to the online community with provided links. The statistical analysis shows $F= 0.42 < 1.93 = Fcrit$, which indicates that the null hypothesis can not be rejected. Professional players did not attract more members with the given subscription links.

Concerning the hypothesis A1 this finding needs to be differentiated. Professional players do show a significantly higher login rate and posting rate, also they do provide significantly more content (in form of game guides) compared to the remaining sample. Their attraction rate for new members is higher on average, yet it is not significant enough to show a statistical difference between the two sub-samples. Although most of the members did not use the given links, therefore their origin is unknown. By focussing purely on the 22 members that did use the provided links, the value of $F= 3.11 > 1.93 = Fcrit$, indicates a statistically significant difference between the professional players and the remaining sample. Overall the results promote hypothesis A1 and indicate that professional users show a higher activity in the online gaming community in several ways, which reflects their "value add" to the platform.

Hypothesis A2: Professional players in the experiment show a higher activity on average in the online community.

This hypothesis is based on two aspects: the average posts per day of membership and the number of logins per day of membership. A higher activity of a member would reflect that he/she is both logging in more frequently and also having a higher number of posts per day on average.

The statistical analysis shows test values of $F= 4.86 > 1.93 = Fcrit$ for the number of posts per day of membership and $F= 2.75 > 1.93 = Fcrit$ for the number of logins per day of membership. In both cases the difference is statistically significant, thus negating the null hypothesis and proofing that hypothesis 2 holds true.

This result is illustrated in Figure 5 (see above); the difference of average posts per day between the two groups is graphically illustrated. The regression analysis between average logins per day and average posts per day in the forum shows a non-significant value of $F= 0.55 < 1.93 = Fcrit$. The two variables therefore are independent and show no significant correlation, both cases "users, who login seldom and post a lot" and "users, who login often and seldom post" exist. Therefore the level of activity should depend on both aspects, since logins could reflect a reading interest; meanwhile posts reflect a discussion/argumentation interest.

Since the quality of posting can differ between users. Therefore each of the posts in the forum was assessed into one of three levels of quality: high, medium and low. The judgment of a posts "quality" is based on the topic relevance, its content and its structure.

After analyzing each of the posts, the distribution of the quality amongst the player was evaluated. No statistically significant difference between professional players and casual players exist in the sample. Generally the level of posts in the online community is comparably high and the overall tone is constructive (the average quality level of the posts exceeds medium).

Hypothesis A3: Professional players have a higher contact rate with other members of the community.

The contact rate of community members depends on their messages send to others and their messages received from others. In order to have a higher contact rate, professional players should at least receive more messages than others. Due to their limited time it is expected that they probably will not answer every single message, still if they would also have a higher number of messages send it would further underline the hypothesis. The number of received messages indicates the necessary criteria and the number of sent messages indicates the sufficient criteria.

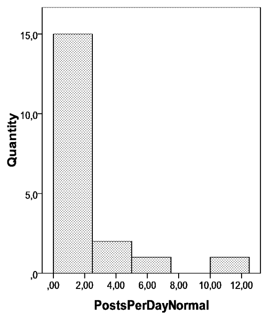
The statistical analysis shows a $F= 0.27 < 1.93 = Fcrit$ for sent messages, which is statistically not significant enough to reject the null hypothesis. Furthermore for messages received $F= 0.64 < 1.93 = Fcrit$, which is also to low to reject the null hypothesis. Both value imply that on average a professional player receives more messages than he/she is sending, although compared with other users of the community, their communication level is not significantly higher. A strong correlation between the number of sent messages and the number of messages received of $F= 126.9 > 1.93 = Fcrit$ shows that nearly all messages are send between a sub-group of the sample. Most of the players did not use the feature of private messages; professional users were statistically no significant exception towards that trend.

Overall this result is counter-intuitive, since hypothesis A3 does not hold true, the professional players do not show a higher contact rate in terms of more activity in the private messaging. Although their average number of private sent and received messages exceeded the number of the casual players, this difference was not significant enough to underline the hypothesis.

Hypothesis A4: Professional players show a higher activity in the "2k+ lobby", since their need for information exchange prevails over their need for social capital.

The hypothesis indicates that professional users will also use the "2k+ lobby" at least as extensive as the normal sections of the forum. A reason for that is

their need for high quality game relevant information, which is higher than the need for social capital. For this analysis descriptive analysis and a two sided T-test are used to evaluate if a difference between these two sections exist. The critical value for the T-test with a sample size of 18 members is Tcrit = T(17) = 2.90, it will be used for the statistical analysis.
The statistical analysis indicates a T-value of T= 2.48 < 2.90 = Tcrit for the comparision between normal and lobby section. This result is relatively close, yet the difference is statistically not significant enough to reject the null hypothesis. Figure 6 shows how similar the distributions of posting in the normal and the lobby section are.



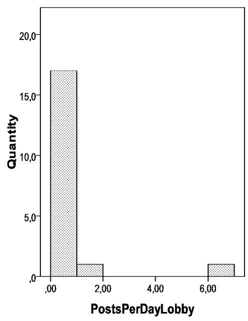


Figure 6: Comparison between average posts per day by professional users in the normal forum section and the average posts per day by professional users in the 2k+ lobby section.

This result indicates two important findings. First, the initial hypothesis that suggests a higher activity of professional users in the "2k+ lobby" could not be shown at the sample. It appears that both areas are used similar by the professional users, which leads to the second finding. Since the T-test is two sided, it also shows that the normal section is not used more frequently than the lobby section.
Therefore it can be concluded, that in the sample both areas have a similar level of interest, none of them is significantly more interesting for the professional players. However this indicates that professional players are willing to trade exclusive game relevant information for social capital to a certain degree. Neither the social capital nor the information exchange are dominant in the perception of the professional players, therefore both areas are used. This finding is counter-intuitive to the initial hypothesis, although the surprising result reflects the importance of both factors for the professional users in the sample.
To a certain degree professional players invest a large amount of their time to achieve brokerage positions. They aim to receive exclusive knowledge in private sections (such as a blog or a forum part) and use this information advantage to gain social capital from casual players. This behavior can be interpreted as a utility maximizing example. Their search for information gives them an advantage in the game and also provides them with social capital from others.

6. Discussion

Do the prior findings necessarily need to indicate a "value add" effect for online communities? Generally the more user independent content is already available within the online community, the lower the additional value of further active users will be. On the other side, the more a community relies on user generated content, the higher a potential gain from an active member will be. This would propose that official gaming communities are receiving a lower "value add" on average from professional users compared to the in-official online communities, since the official online communities already feature a large amount of publisher driven content (like technical support, patches, forum support, etc.).
The analysis of the statistical data provides several findings, some hypotheses are proven, others are rejected and counter-intuitive findings occurred. Overall values add by the professional players for the online community could be shown. Based on their higher level of activity, their more frequent logins, their higher posting rate and their user generated contributions (in form of guides) several aspects show that professional players have a value add for the community.
On the other hand the level of communication with other members has counter-intuitive findings, the professional users do not show a higher rate of private messages sent or received. Still a high correlation between messages sent and received can be shown. Additionally the professional players' need for information exchange and social capital show a differentiated result. Neither of the sections is used more intensively, both the normal and the internal section of the forum show a similar activity of professional players.
Overall these findings support the initial hypotheses of a value add for the online community, yet the motivation of the professional players can only be indicated. Since both areas of the forum are used likewise it appears that professional players are willing to trade-off a higher level of information (in terms of quality, exclusiveness) for a lower level of social capital. The similar usage of the normal forum indicates that this trade-off has its upper limits.
The sample size and the information gathering due to the CMS system provide a high quality level of data. Except the quality assessment of the posts in the forum, all of the other relevant data can be directly quantified and is non-biased.
Although the measurement also has its limitations: Allowing a user to sign up for the forum without an invitation from another user both has its advantages and its disadvantages. The overall larger sample size ensures statistical validity; the low percentage of members using the invite mechanism on the other hand reduces the transparency of a possible lead user influence on direct member acquisition.

7. Conclusion

This paper evaluates the effect of professional users on online gaming communities. Since online gaming communities have their own class in the taxonomy of online communities from Lechner and Hummel (2002), this evaluation describes the first approach to analyze them. Professional players share common traits with typical lead users, yet they differ with regard to their higher needs of current game information and social capital from others.

The approach of this paper introduces the online gaming community "gamersid.eu", which is a pvp-oriented World of Warcraft community, focusing mainly on users of the official game server Theradras.

During the 2 week period of this experiment, overall 116 users participated in the community, contributing five game-related guides, over 300 forum posts and over 100 private messages. This data was stored in the typo 3 CMS system of the online community and statistically analyzed.

The findings of the experiment are differentiated. Some initial hypothesis could be statistically proven. Such as a higher activity of the professional players in terms of logins and posts per day, a higher value add for the online community (for example more guides provided) and a more intense discussion in the restricted area (only access-able for professional-players). Other results are counter-intuitive on the other hand. The data does not support the hypotheses that professional users have a higher contact rate with others and that they will prefer the "2k+ lobby" over the remaining forum. Additionally the results for members acquired show differentiated results as well, mainly based on the low number of overall members, who used the link to invite their friends.

The study distinctly shows that professional users differ significantly with respect of their invested time to gather game relevant information, their number of out-of-game contacts and their motivation to actively contribute to online communities. Professional users are striving to build advantageous knowledge in the course of their interaction with both, game designers (in official online communities) and passive users (majority of other users). Professionalism describes one important motivation underlying the lead-user or community phenomena identified and described in published research. As professionalism seems to reside on personal investments it is decisive force of community dynamics. While many researchers have highlighted the role of social bonds in communities (for an overview see Ren et al. 2007), up to date a limited insight into dynamic factors exists. The motivation of professionals to bridge structural holes seems to be the driving force of community dynamics.

Professionalism qualifies as one decisive dynamic factor that is possibly effective also in other types of communities beyond online-gaming. One implication for community operators is that they should prioritize needs of professional users in the design of communities. E.g. to date most online-gaming communities are structured around games or general interests. Our study identifies professionalism as one factor affecting lead-user characteristics and behaviour. This helps us to provide a deeper understanding of the antecedents of lead-user phenomena, the contributions of lead users to innovation and identification of policies addressing lead-users. So apart from the lead vs. follow role in the innovation process there is an effect of the investor vs. consumer behaviour in the adoption of new technologies or practices.

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ANALYSIS OF USER TRAJECTORIES BASED ON DATA DISTRIBUTION AND STATE TRANSITION: A CASE STUDY WITH A MASSIVELY MULTIPLAYER ONLINE GAME ANGEL LOVE ONLINE

Ruck Thawonmas[1], Junichi Oda[1], and Kuan-Ta Chen[2]
[1]Intelligent Computer Entertainment Laboratory
Ritsumeikan University
1-1-1 Nojihigashi, Kusatsu, Shiga, 525-8577, Japan
ruck@ci.ritsumei.ac.jp
[2]Multimedia Networking and Systems Lab
IIS, Academia Sinica
Taipei 115, Taiwan
swc@iis.sinica.edu.tw

KEYWORDS
Trajectory, Analysis, Online Game, Data Distribution, State Transition

ABSTRACT

At present, trajectory data, series of coordinate data traversed by moving objects, can be readily obtained due to the advent of positioning technologies. Clustering of trajectories and giving meanings to the resulting clusters is an active research area. Recently, we proposed an analysis approach that clusters trajectories in two steps: the first step based on data distribution and the second step based on state transition. In this approach, for coping with the distinguished characteristic of each trajectory, a map of interest is dynamically divided into multiple states, according to the trajectory distribution, and a quadtree is generated for each trajectory. The first-step clustering is then performed based on the differences between the quadtrees. For all trajectories in a resulting cluster of interest, the second-step clustering is further performed based on the differences in their state-to-state transition probabilities using a proposed method for comparing a pair of trajectories with different quadtree structures. In this paper, after presenting a procedure for visualizing a cluster of interest in order to interpret its movement behaviors, we give and discuss a case study where our approach is applied to real trajectory data obtained from Angel Love Online, a massively multiplayer online game, manifesting player behaviors in the target map.

INTRODUCTION

Main objectives in the study of mobile-object trajectories are to understand the current status of a mobile object of interest and to predict its next action or position. Each trajectory represents a series of coordinate data traversed by an object of interest in a given map or terrain. Important technical issues, for achieving these objectives, include (i) determining the distance or similarity between trajectories, (ii) clustering the trajectories based on a given distance or similarity index, and (iii) finding the meaning in each mobile object movement. As for online games, research findings in this particular area are useful in (re)designing a game map of interest as well as the content therein and in providing personalized services to players such as personal route guides.

In related work (Ishikawa et al. 2006; Suzuki et al. 2007), methods were proposed that express and compare trajectories based on transitions between common states. Therein, the target space is divided into multiple subareas, henceforth called *states*, and each trajectory is then expressed by the transition probabilities between those common states. Other methods (Thawonmas et al. 2006; Thawonmas et al. 2007) were proposed that select a smaller number of important states, called landmarks, from the common states and express each trajectory by the landmark-to-landmark transition probabilities. However, use of the common states or the selected landmarks has two problems: over-approximation of trajectory transitions between states and omission of fine movements within a given state. An attempt to solve these problems by increasing the number of states or landmarks will inevitably lead to an increase in computational cost. Rather, the target space should be divided into suitable states for each trajectory, leading to the need for a method for comparing a pair of trajectories with different state sets.

Recently, we proposed an approach (Oda et al. 2009) for analyzing user trajectories that consists of two steps. In the first step, dynamic map division is performed that generates a quadtree, represented by a bit sequence, for each trajectory, and clustering is performed based on the Hamming distances between all trajectory quadtrees. In the second step, for all trajectories in a cluster of interest, their differences in the state-to-state transition probabilities are derived using a proposed method for comparing a pair of quadtrees, and clustering of those trajectories is further performed. Compared to the other approaches, this two-step approach has less computational costs and enables easier interpretation of clustering results.

In this paper, we present a case study in which the above approach is applied to real trajectory data obtained from

Angel Love Online (ALO), a massively multiplayer online game. For this paper to be self contained, the analysis approach in use is described in the next section. After a procedure for visualizing a cluster of interest in order to interpret its movement behaviors, the case study is then given including our discussions as well as interpretations of resulting clusters.

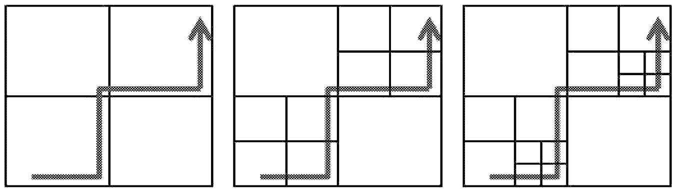

Figure 1: Concept of Dynamic Map Division According to the Trajectory Data Distribution, from Left to Right D=1, D=2, D=3

ANALYSIS APPROACH

1st-Step Clustering based on Data Distribution

For each trajectory, a map of interest is divided according to the trajectory data distribution. Let D indicate the level of division. The initial node (or state) where D = 0, is divided into four areas. After evaluating its data density, each area will be further divided into another four areas if the density is higher than a given threshold. The concept of dynamic map division is depicted in Fig. 1.

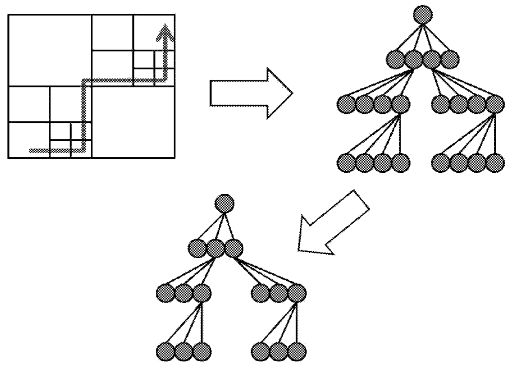

Figure 2: Example of Map Division and the Resulting Quadtrees before and after Deletion of Nodes

A quadtree is used to conceptually represent the resulting division of a trajectory of interest. Under this representation, the initial state is the root of the tree with node number = 0, and incrementally extending the tree corresponds to iteratively dividing the map. At the end of division, if there are some nodes that have no trajectory, all such nodes will be deleted. Figure 2 shows an example of map division and the resulting quadtree.

For subsequent algorithmic manipulation, a unique identification number based on Z-ordering is assigned to each node in every quadtree. Note that all nodes with the same identification number in their quadtrees represent the same area in the given map. A bit sequence for each quadtree is used in quadtree comparison. In each bit sequence, the n th bit indicates existence or nonexistence of the n th node, i.e., if the n th node exists, the n th bit is set to 1; and otherwise 0.

In the first-step clustering, all N trajectories are clustered with the Ward method (Calinski and Harabasz 1974) whose element in the $(N-1)\times(N-1)$ input distance matrix is the distance between a corresponding trajectory pair. For a pair of trajectories of interest, the Hamming distance between the corresponding bit sequences is used. The number of clusters is decided with the rating index introduced in the Calinski and Harabasz's paper, and any cluster with member trajectories less than ten percent of N is excluded because they are considered outliers.

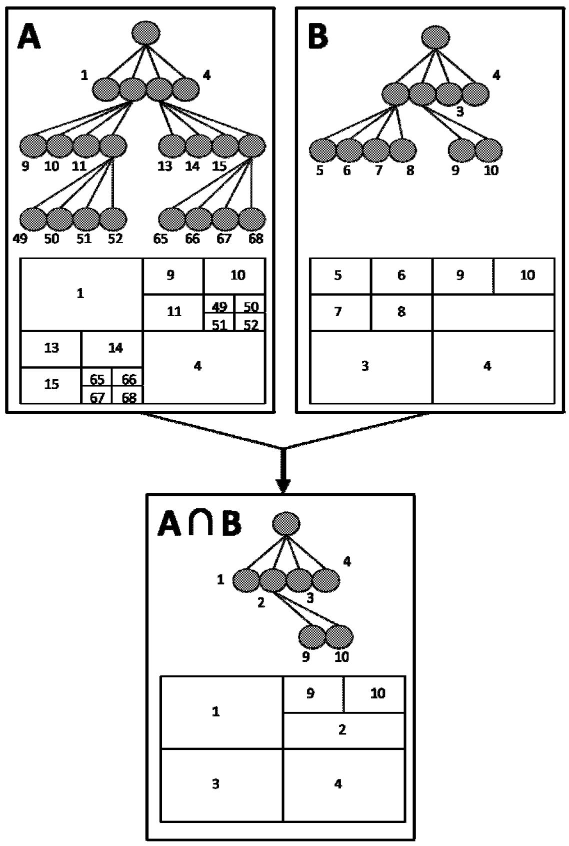

Figure 3: Example of Derivation of a Common Structure for Two Quadtrees A and B Having Different Structures

2nd-Step Clustering based on State Transitions

At the second step, the direction information in each trajectory is approximated by its state-to-state transition probabilities. However, care must be taken here because quadtrees are different from one trajectory to another. As a result, the positions of non-empty elements in their state-to-state matrices are also different. Therefore, for a given pair of trajectories with different quadtree structures, a common quadtree structure is derived by logical multiplication of the corresponding two bit sequences, as shown in Fig. 3 where the node number is assigned to each area.

Once a common structure for a pair of quadtrees is derived, an adjustment is performed for each of their state-to-state transition probabilities associated with any state that unifies its former child states in the original structure. Henceforth, such a state is called a unifying state. For a unifying state of interest, say, state *i*, the transition probability from state *j* to state *i* is the sum of the transition probabilities to the former child states of *i* from *j* while the transition probability from state *i* to state *j* is the average of the transition probabilities from the former child states of *i* to *j* as follows:

i) When only the destination of the transition is a unifying state,

$$a_{ml'} = \sum_{i=1}^{A(l')} a_{ml'(i)} \quad (1)$$

ii) When only the source of the transition is a unifying state,

$$a_{l'm} = \frac{1}{A(l')} \sum_{i=1}^{A(l')} a_{l'(i)m} \quad (2)$$

iii) When both the source and the destination of the transition are a unifying state,

$$a_{l'l'} = \frac{1}{A(l')} \sum_{i=1}^{A(l')} \sum_{j=1}^{A(l')} a_{l'(i)l'(j)} , \quad (3)$$

where a_{xy} is the transition probability from state *x* to *y*, *l'* indicates a unifying state of interest, $A(l')$ contains the indices to all former child states of *l'*. For example, in Fig. 3, if *l'* is 3, $A(3)$ contains 13, 14, 15, 65, 66, 67, and 68. As a result of common-structure derivation, an intermediate node might become a state. For example, in Fig. 3, intermediate node 2 becomes a state.

Next, the distance between two trajectories is defined as the average of the differences in the elements of the corresponding state-to-state transition matrices. This distance is used as an element of the $(N-1)\times(N-1)$ input distance matrix in the second-step clustering, where weights are given to the state-to-state transition probabilities, considering the importance of differences in earlier division levels more important than those in later levels, as follows:

$$w_l = \frac{D_{\max} - D_l + 1}{D_{\max}} , \quad (4)$$

where D_l is the division level of area *l*, and D_{max} is the maximum of D_l. The aforementioned distance between trajectories *i* and *j* is given as follows:

$$Dist_{ij} = \frac{1}{h_{num}} \sum_{l=1}^{h_{num}} \sum_{m=1}^{h_{num}} w_l w_m \left| a_{lm}(i) - a_{lm}(j) \right| , \quad (5)$$

where $a_{lm}(x)$ is the transition probability from states *l* to *m* in trajectory *x*, and h_{num} indicates the number of common states between *i* and *j*. If D_{max} of the common structure is 0, the distance between these particular two trajectories will be given the maximum possible value of (5), i.e., 1. After obtaining the distance matrix for a cluster of interest, the trajectories in this cluster will be further clustered with the same method described in the end of the previous subsection.

CASE STUDY WITH ALO

Figure 4: The ALO Map Used in the Case Study

We present here a case study where our analysis approach is applied to ALO, developed by UserJoy Tech. Co. Ltd, a leading game designer and publisher in Taiwan. This set of trajectory data was collected from the map in Fig. 4 for about 70 hours. In this map, the blue area is a sea on which players cannot move, and the sea separates the map into two sides connected via a small island in the center. In addition, a town, where players go to receive a service (e.g., a quest or assistance) is located near the right of the map center, and monsters, ready to attack nearby players, reside in the left, top-right, and bottom-right regions.

Once clusters are obtained using the analysis approach, we use the following procedure for visualizing a cluster of interest in order to interpret its movement behaviors:

i) Perform dynamic map division based on all member trajectories in the cluster

ii) Visualize the division result with grids in order to elucidate the trajectory distribution

iii) Visualize the major state-to-state transitions with arrows in order to provide the information on trajectory directions.

Table 1 shows the clustering results, where the 1st column and the 2nd column indicate the resulting cluster numbers at the first step and the second step, respectively. At the first step, all trajectories were grouped into two clusters. They were further sub-grouped into 21 clusters at the second step. Out of these, all clusters with the number of trajectories higher than 25, i.e., clusters 1, 2, 7, 10, 20, and 21, are discussed below.

Figures 5 and 6 show the visualized results of clusters 1, 2, 7, 10 and those of clusters 20 and 21, respectively; where the direction of each of the highest ten state-to-state transitions in each cluster is depicted by an arrow, and we note that fine grids with no arrows indicate regions players spent long time. In Fig. 5, grid patterns in the map top of clusters 1, 2 and 10 are similar, and those below the left of the map center of clusters 2, 7, and 10 are also similar. In Fig. 6, grid patterns of clusters 20 and 21 are similar in around the town. From these results, a trajectory is assigned to one of the two clusters at the first step clustering according to whether its distribution concentrates in regions outside or inside of the town. Our interpretation for the first-step clustering is that the play objective of cluster 1 is to mainly fight monsters outside of the town while that of cluster 2 is to mainly use services inside the town.

Table 1: Clustering Results

1st	2nd	Number of Trajectories
1	1	56
	2	28
	3	4
	4	6
	5	5
	6	5
	7	37
	8	10
	9	8
	10	27
	11	1
	12	17
	13	8
	14	1
	15	1
	16	3
	17	2
	18	1
	19	1
2	20	56
	21	117

Now we discuss clusters 1, 2, 7, and 10 in detail considering both map division (grid) and transition (arrow) patterns as follows:
i) In cluster 1, because of an arrow between the left and right sides of the map and fine grids in the top-left region, these players moved back and forth across the small island to fight monsters in the top-left region and to use provided services in the town.
ii) In cluster 2, having many arrows in the bottom of the map indicates that these players repeated fighting those monsters therein, and, because of fine grids in bottom-left quarter of the map, some events might have occurred and thus attracted players to the region.
iii) In cluster 7, because arrows and fine grids can be seen in the bottom of the map, players in this cluster concentrated on fighting monsters.
iv) In cluster 10, arrows from left to right across the small island and fine grids in the bottom indicate that these players started movement from the top left of the map and then went to the right side in order to fight monsters down there.

Our interpretations for clusters 20 and 21 are as follows:
i) In cluster 20, because of many arrows and fine grids are seen near the map center, players of this cluster repeatedly visit the town in order to use services provided therein.
ii) In cluster 21, because arrows and fine grids below the town and the top right of the town, these players repeatedly visited the town and then went to fight monsters.

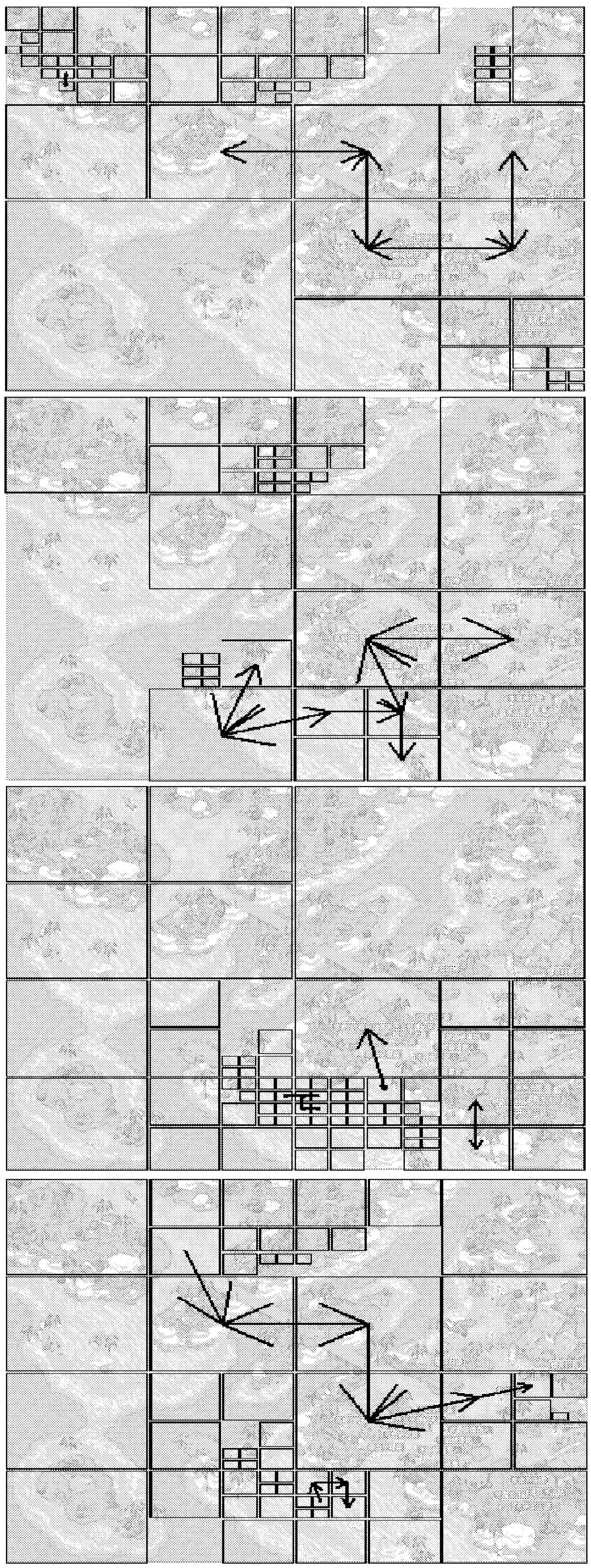

Figure 5: Visualization of Divisions and Transitions for, from Top to Bottom, Cluster 1, Cluster 2, Cluster 7, and Cluster 10

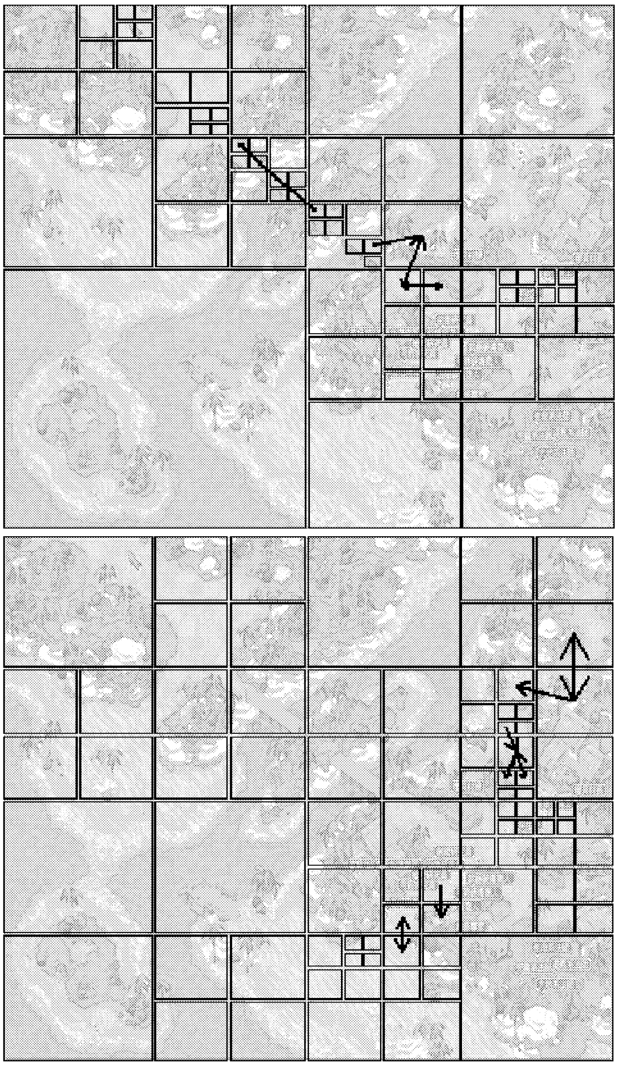

Figure 6: Visualization of Divisions and Transitions for, from Top to Bottom, Cluster 20 and Cluster 21

CONCLUSIONS AND FUTURE WORK

This paper presented a case study where we applied our recently proposed analysis approach to ALO trajectory data. A procedure for visualization of the resulting clusters was given. Interpretation of movement behaviors in each major cluster was conducted based on the visualized results and the a priori knowledge of the map context. In order to deepen understanding of players, a technique (Thawonmas and Iizuka 2008; Drachen et al. 2009) for clustering players according to their action behaviors and visualizing as well as interpreting the clustering results can be used together with the proposed analysis.

From trajectory data, movement speed can also be derived. The information on speed is useful for finding the detail meaning in mobile object movement. In future, we plan to incorporate the speed information into our approach and to experiment it with other kinds of movement data, such as player trajectories from pervasive games and those in 3D virtual museums (Sookhanaphibarn and Thawonmas 2009). Another future work is to apply the proposed analysis approach to our on-going development of believable (human-like) AI bots (Hirono and Thawonmas 2009) in the first person shooting genre, where understanding of human player behaviors plays an important role.

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EDUCATIONAL GAMING

RECOMMENDATIONS TO MAKE GAME ENGINES MORE ACCESSIBLE TO EDUCATORS AND STUDENTS

Penny de Byl
Academy of Digital Entertainment
Breda University of Applied Sciences
Breda,
The Netherlands
E-mail: penny.debyl@gmail.com

KEYWORDS
Game Engine, Serious Games, Education

ABSTRACT

Serious Games are big business, however not many of them are finding their way into the classroom. The number of teachers integrating games into their curriculum is far from a critical mass. Many previous research studies have found the primary barriers to educational game use in schools are mostly focused on the teacher's lack of technical expertise and knowledge of games in addition to already overburdened workloads. Rather than revisit these issues and solve them we are asking what game engine developers can do to make their products more accessible and easier to use so that time poor technical novices such as teachers can bring the benefits of computer games to their classroom. In a survey of 16 educators developing educational games we have found the key functional requirements of a game engine to be focused around the provision of comprehensive tutorials, a supportive online community and documentation.

INTRODUCTION

Today's students who demand more from their educational experiences than flat pages of content, un-interactive videos and text based communication software are no longer engaged by educational materials deemed acceptable in the past. They are more attuned to engaging and fun high quality 3D entertainment software such as computer games (de Byl and Taylor 2007). Making educational activities fun, immersive and engaging is one of the goals of today's educators (Clark 2007). When we think of fun there is an immediate tendency to think towards games. Games not only make education fun but they can also place learners into realistic role-playing situations with a set of goals to achieve ((Kafai 2006), (Gibson 2007), (Prensky 2008)).

However, implementation of such technologies in schools and universities has inherent problems as traditionally they have been the domain of technical experts (de Byl 2009). Most game development exercises require some degree of programming expertise. What is clear from previous research is that for a successful paradigm shift towards enhancing learning and teaching technology teachers need to be shown how to access the required resources, make use of these resources and the resulting applications (Rogers 2000).

Previous studies into the reasons why educational games are not making it into the classroom have focused on the teachers' situations. The results have shown a lack of teacher expertise and available time to be the key factors influencing the resistence. In contrast, the pilot research presented herein focuses on game engine functionality and examines what 16 educators developing their own games consider to be crucial functionalities for authoring environments.

This paper beings with a brief overview of the use of games in the classroom followed by a summary of the practical barriers preventing more widespread use of educational computer games. After this the results of a survey are presented listing the essential and not so essential elements which will provide a guide to game engine creators of the needs of educators and students wanting to use their products in the classroom.

BACKGROUND

Many enterprising and motivated educators are using computer games in their classrooms to supplement traditional learning activities. They do not necessarily have the expertise to create their own games and have found a solution in existing computer games, customized computer games and virtual environments.

Commercial Off-The-Shelf (COTS) games are used in the classroom beyond the vision of the original developer. They are being used, for example, to teach skills ranging from literacy (LTS 2009)to observation and creative writing (Kirriemuir 2005) to physics (Price 2006).

The most widely and successful use of gaming technology used in educational institutions to date, which has found a considerable critical mass of users is the online virtual world (Kluge and Riley 2008). For example, *Second Life* has attracted more than 260[1] educational institutions and *Active Worlds*, 122[2]. Educational applications in these domains range from the aesthetic viewing of software (Fishwick 2008) to midwifery (Stewart 2008).

[1] Source: SimTeach.org
[2] Source: ActiveWorlds.org

There is however, another use of gaming technology in the classroom which has proven benefits beyond game playing; game development. Many researchers have found the development of games to reignite student interest in courses, provide motivation to develop IT skills (Werner, Campe et al. 2005), develop problem solving skills through engaging activities (Chamilliard 2006) and build narrative skills (Robertson and Good 2005). For these types of game development activities both educators and students require access to game engines. While a handful of game engines such as *Game Maker* (http://www.yoyogames.com/make) and authorware such as *Adobe Flash* have proven popular with teachers there is a plethora of open source game engines available for making even more visually stunning and engaging serious games though they have not found their way into mainstream schools.

The practical barriers to acceptance and uptake of these engines are many ranging from institutional policy, ICT infrastructure and teacher training and confidence. Some of these issues will now be discussed.

BARRIERS TO UPTAKE

Although some supporters of computer game use in education have envisaged a bright future for the technologically advanced classroom with cheaper high speed hardware, miniturisation, wireless networks and unlimited online virtual storage space (Madeja 2003) this is simply not the case. From researcher's reports (Plante and Beattie 2005), (Farrell and Isaacs 2007) and the author's own experience with universities and schools in The Netherlands and Australia, staff, student and laboratory computers are not bought with games in mind and therefore lack the necessary graphics cards, processing speeds and virtual memory. A brief random survey of the minimum personal computing requirements for students from several universities and K-12 schools reveal computers can range from Pentiums to Intel Core 2 Duos and few consider dedicated graphics cards (as shown in Table 1).

When the minimum requirements to run most game engines is in excess of those specified by educational institutions it makes the first hurdle in bring games into the classroom, the classroom itself. With popular game engines like *Game Maker* requiring a DirectX 8+ compatible graphics card with 32Mb of memory, 64Mb RAM and a 500Mhz processor and *Flash CS3* requiring 1Gb RAM and a 1Ghz processor, these *entry level* rapid game development tools are also out of reach of most students and educators.

In addition to the figures in Table 1, a survey of schools in Canada conducted in 2004 found that 47% of schools (n=154) had computers with medium processing speeds (233Mhz) and the student-to-computer ratios of 5:1 were the highest internationally, inline with the U.S.A and Australia at the time (Plante and Beattie 2005). A recent Australian report has indicated in 2008 the student-to-computer ratio across all schools remained at a median of 5:1, the best being 1:1 and the worst 101-800:1(Government 2008).

Table 1: A brief survey of school mimimum computing requirements

Institution	**CPU**	**RAM**	**Graphics**	**Speed**
NC State University	Core 2 Duo	2Gb	None	N/A
Texas Tech University	Core Duo	2Gb	256MB Nvidia Quadro	1.66 GHz
University of Southern Queensland	Pentium	256Mb	64MB VRAM	1 GHz
University of Wollongong	Core 2	2Gb	128MB VRAM	2 GHz
University of Hull	N/A	1Gb	None	N/A
Deakin University	Celeron	1Gb	None	1 GHz
Champlain College	Core Duo	2Gb	1GB+	1.88 GHz
K12 International Academy	Pentium III	256Mb	None	500 MHz
K12 Free Homeschool	Pentium III	256Mb	None	N/A
Internet Academy	Pentium III	256Mb	None	N/A
Minnesota Online High School	Pentium II	512Mb	None	233 MHz

Besides hardware limiting what game engines are available to educators, other barriers as reported (Becker and Jacobsen 2005) are displayed in Table 2 and include inadequate teacher training and technical expertise, lack of time and access to computers.

Table 2: Common Barriers to Uptake of Games in the Classroom

Barrier	**%[3]**
Lack of Time for Projects that Use Games	81.0%
Not Enough of Limited Access to Computers	72.7%
Games Integration not a School Priority	70.7%
Not enough teacher training opportunities	66.0%
Students have insufficient access to computers	62.5%
Lack of adequate technical support	59.3%
Difficulty finding subs in order to attend training	55.2%
Lack of support for adequate supervision of students	49.5%
We have no audio facilities	46.3%
Our Machines Can't run Games	45.3%
No training available	41.8%

With these barriers in mind we conducted a survey of educators who use games in the classroom to gauge the functionality and requirements of a game engine which they thought to be most important. Educators were asked to particpate in the survey via the *Games Research Network* and *International Game Developers Association Special*

[3] Percentage of respondants who indicated the barrier (n=109 K-12 schools in Alberta, Canada)

Interest Group on Games in Education mailing lists. The call for participants produced 16 completed surveys. Although a disappointing sample size, the results are none-the-less useful as a starting point for determining educators' opinions.

SURVEY RESULTS AND DISCUSSION

The first part of the survey asked participants to rate the importance of a list of functionalities with respect to their inclusion with game engines. The results indicate the importance of educational materials about the game engine itself. The participants rated online documentation and comprehensive tutorials more important than other functionality (almost twice as important as *open source* or *free software*). These results are shown in Figure 1.

Participants were also less interested in the game engine being available on platforms other than Windows and indifferent about it being usable by technical novices. These results are in contrast to the author's actual experience with high school and university teachers with little programming expertise having found both the lack of programming skills and lack of cross platform functionality to be a barrier to the mainstream use and acceptance of games.

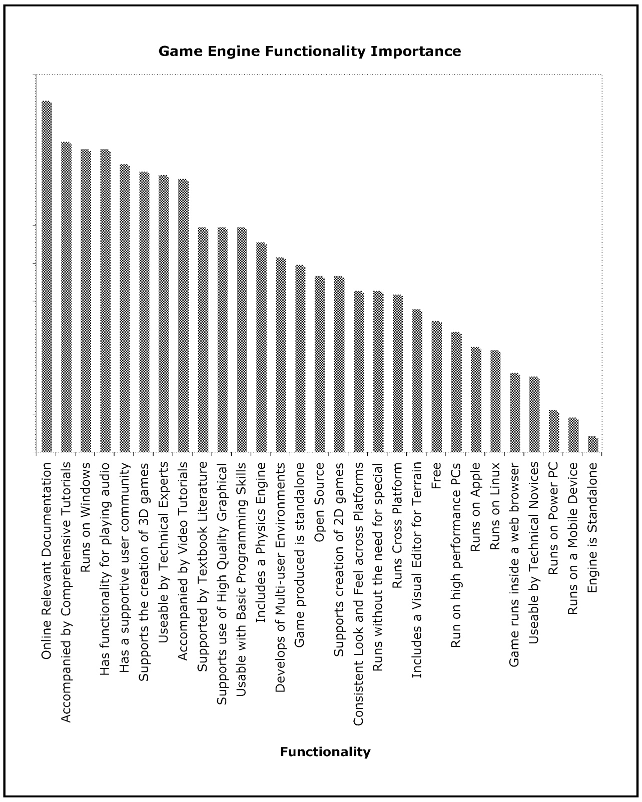

Figure 1: Level of Importance of Functionalities

These particular outcomes might be explained by the participants' obvious desire and use of educational games having been involved in the before-mentioned mailing lists. In addition, further data collect as shown in Figure 2, indicates the majority of participants to be from the educational domains of information technology and computer science. Hence we assume they are somewhat technically skilled with respect to creating computer games.

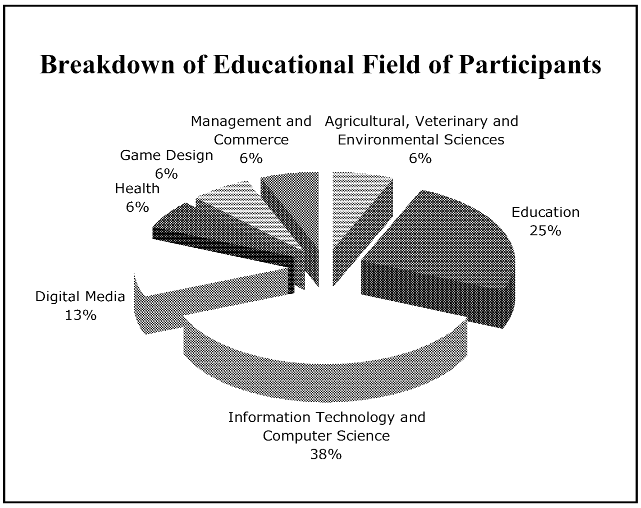

Figure 2: Survey Participants' Educational Field

Additional evidence of this expertise is shown in Figure 3. The results here indicate that the participants considered the C language and various derivatives (including C++) to be critical languages which should be included as a programming interface to a game engine.

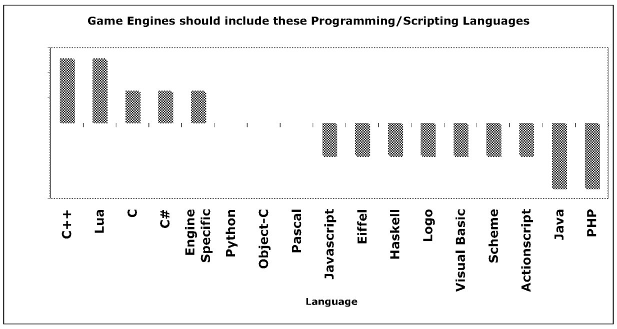

Figure 3: Languages which should be included

Despite a preference for C like programming interfaces and indifference for Actionscript, interestingly Flash was indicated as the most highly used engine, as shown in Figure 4.

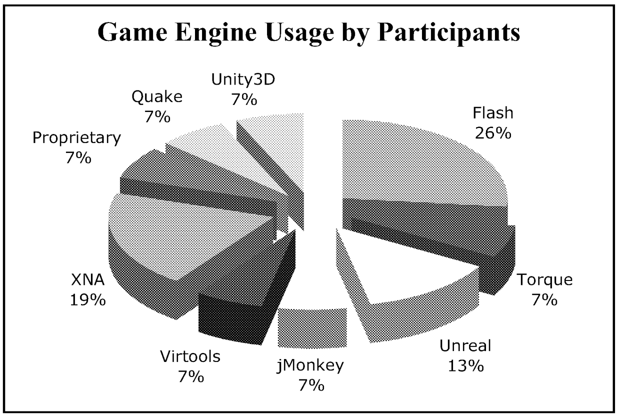

Figure 4: Percentage of Participants using specific game engines

In hindsight the participants chosen for this survey were not the ones to investigate with respect to narrowing down a list of the essential functional requirements of game engines for use by non-programming teachers and students. However they have provided valuable insight into what they feel is important and which game engines are actually being used for their purposes.

What this pilot study does support is the preposition of the importance of providing teacher training, online documentation, an active user community and comprehensive tutorials. In addition, it has provided further incentive to access educators who are not using games in the classroom and to compile a list of their functional requirements.

CONCLUSIONS AND FURTHER WORK

Although the idea of creating effective, engaging educational games is alluring the reality is that creating professional applications, including three-dimensional games and simulations, requires specialist skills and knowledge. Thus, despite the unique benefits of these environments to deliver effective pedagogical methods which include self-motivation, self-directed learning and learner commitment, such development activities are often beyond the technical skills of most students and educators.

The previous studies conducted by other researchers have sought to determine the reasons why games have not been widely embraced in the classroom. These have focused on teachers' and schools' circumstances and found the lack of time, knowledge of game/classroom integration and ICT infrastructure to be the major barriers. Instead we've investigated the situation from a different angle and addressed the user requirements that might help improve the usability of games engines by teachers and students with little or no programming experience. Although the survey respondents turned out not to be technical novices, as indicated by their educational domain and programming preferences, the results have assisted in focusing future research efforts.
With teachers having very little time and resources in which to learn games and deploy them in the classroom we hope that through our research we can target game engine developers to make products which are accessible and drag-and-drop user friendly.

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BIOGRAPHY

PENNY DE BYL teaches computer games programming, serious games theory, and research methodology at Breda University in the Netherlands. In 2007, de Byl won the state government of Queensland's Smart State Award for her work with the Advanced Learning and Immersive Virtual Environments (ALIVE) project, which was followed in 2008 by an Excellence in Teaching award from the University of Southern Queensland and a Research Fellow Award. de Byl has published numerous international conference papers, journal papers, and book chapters as well as two books in the areas of artificial intelligence programming for computer games. She is also an associate editor for the *International Journal of Gaming and Computer-Mediated Simulations*.

de Byl's areas of interest include e-learning, serious games, augmented reality, and distance education systems. Since 2006, she has managed the creation of more than ten serious games covering areas such as mathematics, astronomy, fire evacuation, and behavioral management. Her current projects include the use of computer game technology for augmenting the classroom with virtual computer-generated objects and empowering educators with easy-to-use tools for creating learning and teaching applications.

MATH GAME(S) – AN ALTERNATIVE (APPROACH) TO TEACHING MATH?

Anton Eliëns [1,2] and Zsófia Ruttkay [2,3]

[1] Intelligent Multimedia Group, VU University Amsterdam
[2] Creative Technology, University of Twente
[3] Moholy Academy of Arts, Budapest, Hungary

KEYWORDS
games, mathematics, learning

ABSTRACT

Getting students to read, digest and practice material is difficult in any discipline, but even more so for math, since many students have to cope with motivational problems and feelings of inadequacy, often due to prior unsuccesful training and teaching methods. In this paper we look at the opportunities offered by computer graphics, visual programming and game design as an alternative for traditional methods of teaching mathemathics. In particular, games may be deployed both as intruments to drill concepts and skills, but in addition as a way to identify challenges and possible strategies for solving problems in the mathematical domain. Our, perhaps somewhat optimistic, message is that, when coupled to instruction of visual programming, web technology and new media deployment, students gain insight by constructive explorations in a wide variety of mathematical problems. Moreover, by creating their own game worlds, reflection on the structure and complexity of mathematics is encouraged taking each student's capabilities and limitations into account, thus avoiding the fear of mathematics that haunts so many students.

INTRODUCTION

In Eliens & Ruttkay (2009) we observed that *educators continuously face the problem of motivating their students to learn, to consult textbooks, do exercises, reflect on the material, and repeat this cycle over and over again.* For mathematics this problem is even aggravated by the lack of motivation of students, or in many cases even fear and feelings of inadequacy due to prior unsuccesful training and teaching methods that do not align well with the needs of the students. That is, however, not to say that, as many seem to do, the mathematical skills of undergraduate students are declining, which we believe not to be the case, but that a proper context is needed to deploy these skills effectively. In this paper, we will report on our experiences, and in all honesty, our intentions, to make learning mathematics appealing to students of a variety of flavors, that is across both the technical as well as the more society and arts oriented profiles of students. Our approach is strongly motivated by the need expressed by designers as well as artist to become *familiar with mathematics* in order to better understand the visual effects of complex phenomena, e.g. Lundgren (2006). Another motivation and the actual background to our work is the need to bring mathematics education to artists and creative engineers, in both the Netherlands and Hungary.

Inspiration and support for our attempts to bring mathematics and computation to the attention of artists and creative engineers, and enrich their set of skills, comes among others from the *processing*[1] community, that has arisen out of a long-standing tradition of what may be characterized as *aesthetics by numbers*, pioneered at MIT, Reas & Fry (2008). Computation and mathematics have been adopted by new media artists, using *processing*, *flash* and other graphical frameworks with stunning works, available in many online galleries all over the web, see for example Jared Tarbell's Computation Gallery[2]. For (future) game designers and developers, knowledge of mathematics needs no argument, as exemplefied by the many sites about game physics and math for game designers[3].

structure The structure of this paper is as follows. First we will sketch our motivations and the background for this work, that is the educational context in which our developments take place, then we will present our first attempts of defining a taxonomy and overview of the use of computer graphics and games related to mathematics education. After that we will present our insights and (limited) experiences with using visual programming and game design in teaching mathematical concepts. With an overview of available tools and technologies, focused, in particular on the presentation of math and graphics on the web, we conclude this paper by outlining how we think to deal with the motivational issues that provided the inspiration of our work, as well as issues for future research and development.

[1] www.processing.org
[2] www.complexification.net/gallery
[3] gamemath.wikicomplete.info

MATH IN THE CREATIVE TECHNOLOGY CURRICULUM

At our university, we are currently developing the new BsC curriculum Creative Technology[4], with a paradigm shift compared to traditional academic education, advocating exploratory learning of maths and programming. See our blog at creativetechnology.eu

We are not the only ones to observe that the attitude of our pupils and students is changing. The young generations of our days are:

student(s)

- highly visually oriented, they see and learn by trying out things rather than consulting traditional textbooks;
- proficient with using computers (games) at early age,
- less interested in science, and particularly, in mathematics, and do not perform well in these respects in many Western societies

This trend is to be noticed by the decay of interest in programming and mathematics academic educations in many countries, and the attempts of using interactive games and computer graphics as attractive vehicle towards these disciplines, Duchowski & Davis (2007).

We observe that the power of visual representation and active involvement (including manipulative tasks) was identified as key to education from the earliest times. Nowadays videogames hold a strong promise to that effect, Gee (2003). Also in maths education the 'manipulative' power, albeit without computer, has been proven valuable decades ago. Interactive games and computer graphics open new ways for mathematical investigations exploiting visual, manipulative and explorative aspects.

TOWARDS A TAXONOMY OF MATH GAMES

To determine how games and interactive graphics can be used in math education, we present a (preliminary) classification of games related or involving math. For a more extensive discussion, with illustrations, see Ruttkay & Eliens (2009).

taxonomy of math games

1. games to practice routine tasks
2. manipulative virtual environments for *try-out*
3. simulations for making conjectures
4. strategic games – manipulative & combinatorial
5. visualization of structure(s) – patterns of nature
6. explorations in 2D and 3D geometry
7. generative (visual) art

Simple computer games (1) may be seen as a wrapping to practice some repetitive routine task, like mental arithmetic. Classical puzzles (2) include the 3 jars problem requiring to measure some k liter of water having empty jars of m and n liters and a full jar of n+m liters[5]; or the puzzle of 3 cannibals and 3 missionaries who all need to cross a river and remain alive, using a 2 persons boat[6] as well as the wolf-goat-cabbage puzzle[7]. For many mathematical questions (3) it is useful to check empirically many concrete cases, in order to gain some insight and guess the answer (which will then have to be proven). The design and interpretation of the visualization is straightforward for problems of geometrical nature (or ones which have a natural geometrical analog), as well as for guessing probabilistic distributions. But e.g. visualizing number distributions may provide surprising beauty as well as some mathematical insight[8]. Combinatorial graph games (4) involve the finding of some characteristic subgraph (Hamilton path, Euler path), or changing the graph in an iterative way (against an opponent) to reach some goal. For young kids, the graph may be presented in a real-life context, as roads in a town[9]. Natural forms (5) lend themselves as excellent topics for experimentation with parametric generation and mathematical analysis of these forms, and the underlying generation mechanisms. Similarly, Perlin noise is an excellent vehicle to learn about probability, and shown as basic principle for computer-generated natural phenomena, ranging from mountain highlights to flocking behaviour. For these phenomena, there seems to be ample teaching material[10]. In interactive geometry applications (6), a drawing usually illustrating some theorem in planar geometry can be modified by dragging some point on it, resulting in adjustment of the other, related points and lines. We developed an interactive environment to reproduce historical drawing machines[11] that allows children to explore various geometrical transformations, Ruttkay (2008). As an interesting example of generative art (7) we mention Vera Molnar[12].

LEARNING MATH BY VISUAL PROGRAMMING AND GAME DESIGN

In the previous section we have indicated how games and interactive CG applications can enhance maths

[4] create.ewi.utwente.nl

[5] www.cut-the-knot.org/water.shtml

[6] zap.psy.utwente.nl/zaps/zaps/zaps/kannibalen.res/frames.html

[7] www.mathcats.com/explore/river/crossing.html

[8] www.numberspiral.com

[9] www.coolmath-games.com/0-loopthecity

[10] www.shiffman.net/teaching/nature

[11] wwwhome.cs.utwente.nl/∼zsofi/machines

[12] www.atariarchives.org/artist/sec11.php

education. These, however, may easily lead to a passive attitude and no more than a scattered understanding of the mathematical principles involved. As the value of the construction of proofs by pupils themselves is well-recognized in traditional approaches to teaching mathematics, we also must consider the value of visual programming and game design assignments. Such assignments could range over creating some of the previously discussed examples, e.g. developing generative grammars for producing visual patterns, Terzidis (2008), programming simple physical systems with collisions, Peters (2006), or even the implementation of casual games. Such assignments would require the understanding of certain mathematical principles (e.g. Newtonian motion) while adopting them for a goal, or even would raise genuine mathematical challenges (e.g. getting insight into an invented strategic game). But the domain of the game itself may be mathematical as well one could think of inventing a game for graph exploration exercises, or devote a game to the life and work of some famous mathematician.

In developing our curriculum for the Creative Technology bachelor, we have chosen to adopt this more constructive approach to teaching and we have set ourselves the goal of assembling a coherent set of assignments, complementing our lectures in math, that allow the students to become intimately familiar with the mathematical principles involved in their (creative) engineering practice, by hands-on programming experience, with a clear focus on visual programming and game development.

To enable the actual incorporation in our curriculum, we have planned, apart from a limited number of traditional math courses, a new course creative explorations, that will introduce a number of mathematical topics, which we consider to the distress of some mathematicians the *heart of mathematics*, some directly related to mathematical aspects of design, such as generative algorithms, geometry, perspective and noise, but others of a more distinct abstract nature, to make our students familiar with the reasoning underlying mathematics.

As we will argue in the next section in more detail, such an approach nowadays is made feasible by a variety of tools and techniques.

To promote a coherent application context of the fragments, to be developed by students, we formulate the outline(s) of a mathematics adventure game, centered around a (not entirely fictitious) figure, Mr. E:

Mr. E's knapsack

> Mathematician Mr. E is traveling the world with his knapsack full of (mathematical) knowledge. Exploring the world, he meets famous colleagues like Euclid, Euler, Gauss, Newton, Einstein, Gödel, Leibniz, etc. He has to collaborate - learning as well as teaching - to proceed, get goods, get a regenerating cup of coffee, and sometimes a place to stay. He uses his problem solving skills to discover the world, and to unravel it's Big Mystery. Mr. E's journey is taking him around the globe and through the history of science and mathematics.

Mr. E's knapsack is meant to be an adventure game in historic and scientific setting, which combines the attractiveness of a fantasy world as in games like Zelda and Star Wars, with education, by providing a context that is on the one hand fictional, but on the other hand provides scientific knowledge and historic information. It lets the character learn 'real' uses of mathematical items, since the player has to actively use such items somewhere else in the game, e.g. pick up a theorem at Euler and use it to solve a problem posed by Gauss.

This brief scenario stems from a group of mathematics (master) students of the University of Amsterdam, and originated in the first place from the wish to get a more clear idea on how all the mathematics concepts learned fit together, and in the second place to create an environment to teach mathematics in an integrated way, supplementing ordinary textbooks, ranging from high-school students to advanced master-level students. It is also meant to play a role in their work for De Praktijk[13], a company that develops new concepts for natural science education, primarily targeting high-school students.

An adventure game, that we take as a convenient metaphor for an online mathematics textbook, provides flexible access to a variety of illustrations and exercises dependent on the skill level of the students, and allows for extensions by student-created content both visual (e.g. generated plants) and intellectual (e.g. a question raised for the future players). In addition interactive video may be used to provide the necessary historical and societal context, Eliens et al. (2008).

MATHS ON THE WEB – FRAMEWORKS AND TOOLS

When Java applets were introduced about a decade ago, there was a general enthusiasm among educators, at least in CS departments, that their topics - mathematics, programming languages - could be presented in an interactive way. However, although Java has been adopted as the programming language of choice at many universities, the early vision(s) of interactive education has not been realized, despite the increasingly large collection of interactive examples of mathematics, physics, and related disciplines on the Web. When we look at how, for example, Wikipedia has become a trusted source of information on mathematics, we may attribute this to the lack of a coherent framework for

[13] www.praktijk.nu

incorporating interactive math examples. Such a framework, apparently, is more easily provided for (hyper) textual information, or images and video, as testified by the large amounts of user-contributed content in sites such as flickr and youtube.

Is it possible to create a similar repository for samples of interactive mathematics, and, on a more modest scale, to formulate guidelines to enforce a coherent approach in both (visual) style and (mathematical) content?

In developing our Creative Technology curriculum, we discussed computer programming platform options ranging over C++, flash/actionscript and, of course, Java. Finally, as indicated before, we have chosen for processing, as a language to teach programming, but foremost as a platform for exploring both mathematical and visual ideas in an exploratory fashion using computational means, suited for educating creative engineers. Although, clearly, we strongly endorse the visually-oriented programming-by-example paradigm supported by the processing environment, we will in a later phase of the curriculum also introduce other programming environments, in particular javascript/php, flex/as3, C++ with suitable libraries, as well as one or more of the many game engines and game development platforms such as Unity3D and the Half Life 2 SDK. Where the choice for processing was motivated by both ease-of-use and ease-of-learning, the other platforms and environments are primarily motivated by reasons of deployment, that is the means available by our (target) audience. In our efforts to decide on a first programming language, we found that processing libraries are available for both javascript[14] and (Open Frameworks[15]) C++, enabling a direct transfer of skills and knowledge. when using *processing* to teach (introductory) programming. Adobe flex/as3 would provide a strong alternative, not only with regard to popularity of the flash player, but also looking at issues of efficiency and support for graphics. For example, the effects that can be obtained using pixelbender[16] shaders, using relatively simple mathematical formulae, are simply stunning. However, we found that the flash CS3/4 tool would rather confound our methods of teaching. Also, the many examples made by code-artists, as they are called in the *processing* community, seem to fit the targets we set our students better than the bewildering amount and variety of flash examples.

MOTIVATIONAL ISSUES – THE HEART(S) OF MATHEMATICS

Mathematics, by nature, is an abstract and mental discipline. The formal notations and the among mathematicians agreed rules of deriving proofs form the basis of the traditional pure mathematical textbooks, reminiscent e.g. of the style of the Bourbaki school, Aubin (1997). While reading such a pure and formal work may be considered as the way of coding and transferring mathematical knowledge, and provide high intellectual (even, aesthetical) pleasure for the professional, it does not raise the interest or provide an entry to grasp the very idea and the essence of the topic, neither the (exploratory) road of discovery to it, in an individual or cultural-historical context. However, accounts on mathematical discoveries are rich in visual representations, enlightening analogical stories, inspirations gained by observation of (natural) patterns, Chalmers & Cunningham (2002), and as such an excellent topic for a visually appealing adventure game.

guidelines for a maths adventure game A loosely coupled collection of game components, organized as an adventure game, is a excellent means to avoid the linear format of traditional textbooks, and by allowing students to contribute content, a unique facility to learn mathematics by exploration, as well as, actively, constructing (computational) samples themselves. A detailed description of the architecture of such a system, however, is outside the scope of this paper, and, clearly, an issue for further research. Perhaps more important than the possible technical solutions is to indicate what type of interaction we wish to achieve, and how guidelines with respect to visual style may be enforced.

As for interaction, interesting examples are provided by a collection of physics-driven construction game(s)[17], where vehicles must be assembled that will then either roll to their destination or crash halfway, dependent on the skill of the player, and, roughly based on the same principles, the Magic Pen[18] game where the player can simply draw shapes, that then get a life dependent on the physical laws at work. Both games, in our mind, however, are lacking in (aesthetic) visual style and, frankly, too childish. An interesting example of a game where game play is determined by drawing is MijnNaamIsHaas[19], meant to teach children vocabulary (in Dutch). Dependent on the vocabulary learnt so far, the game reacts on the childs drawing, intelligently, by generating additional content. Using a simple line style, with simple visual effects mimicking child-like drawing, this game may act as a reference for the aesthetics of our mathematics adventure game, where intelligent drawing tools obviously may play an important role in interaction, and applying well-established techniques of code-generation, be used to store code-fragments in a database of game components.

[14] processingjs.org
[15] www.openframeworks.cc
[16] labs.adobe.com/technologies/pixelbender
[17] funnygames.nl/spel/constructie_bouwer.html
[18] magic.pen.fizzlebot.com
[19] mijnnaamishaas.nl

CONCLUSIONS AND FUTURE WORK

It is apparent, when browsing through resources, how many applications lack aesthetic appeal and design wit, usually because the author is a computer scientists or mathematician not equipped with the skills, or the environment he/she used to create the content does not provide good support for the visual design.
From an educational, or if you will, methodological point of view, games and interactive CG may be used:

methodology

- as a means to provide illustrations or trigger interest
- in assignments to exercise routine tasks
- to enhance the curriculum (additional explorations)
- as the major theme and medium to teach mathematics
- (and) to learn algorithms and programming

In our assessment, the above list also indicates the big jumps in challenges to develop the kind of application - starting from stand-alone puzzles via explorative environments to full-fledged interactive course materials. The challenges encompass both technological/design and mathematical/pedagogical aspects.
By setting our ourselves the goal of a comprehensive mathematics adventure game, we not only hope to improve our teaching of mathematics, but also find appropriate styles and patterns that may guide the development of math (related) games and applications, Björk & Holopainen (2005).
In conclusion, answering the somewhat provocative question in the title of our paper, *no*, (math) *games will not replace* (traditional) *math education*, but (may) augment it with challenges and explorations, supported by the new developments in technology.

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Anton Eliens (PhD) is lecturer and coordinator of multimedia at the VU University Amsterdam, and was recently appointed at the University Twente as professor creative technology / new media. He has been closely collaborating with Zsófia Ruttkay and is experienced in web-based interactive media, interactive video, and the application of such technologies in serious games.

Zsófia Ruttkay (PhD) is Assoc. Prof. at the University of Twente and headed the Creative Technology Working Group. Trained as a mathematician, she has expertise in creating styled multimodal behaviour and communication strategies for virtual humans. She also has a strong interest in educational game. Since september 2009, she is professor at the Moholy Academy of Arts, Budapest, Hungary

GAMING FOR REAL WORLD ENGINEERING ENVIRONMENTS

DETECTING STRESS USING EYE BLINKS DURING GAME PLAYING

M. Haak, S.Bos, S.Panic and L.J.M.Rothkrantz
Faculty of Electrical Engineering, Mathematics and Computerscience
Delft University of Technology
Faculty of Applied Sciences
Netherlands Defence Academy
E-mail: L.J.M.Rothkrantz@tudelft.nl

KEYWORDS
Computer games, Emotion, StressNeural Networks, Brain Computer Interface, Cognitive Psychology.

ABSTRACT

In this paper, we research the amount of stress during gamepleying and the impact of visual features in the background of the game. We present our findings on detecting eye blink artefacts in brain activity using EEG. A test subject participated in a car driving simulation and his brain activity was captured during the experiment. While driving, stressful emotions were triggered in the participant, through steep curves and attention seeking billboards. Our research shows that detecting eye blinks is possible using a low cost EEG solution. We use the longitudinal differences of two prefrontal cortex sensors in combination with amplitude maps to classify eye blinks. We correlate eye blink frequency with experienced stress, observing higher frequency of eye blinks in stressful situations. Furthermore, we show that brain activity is significantly more active when doing mental calculation with eyes open as opposed to doing them with eyes closed. Results of this research could be used by game designers to control the amount of stress during game playing.

INTRODUCTION

The human brain is considered a black box by many scientists. Although we are able to model and explain some phenomena, the majority of the brain's workings are still a mystery. The brain's activity can be measured using detection of electrochemical signals, blood flow and possibly others. When looking at the electrochemical signals, a large problem is linking these signals with a specific activity, such as activating motor functions or solving math equations using mental calculations. It is even harder to generalize the interpretation of these associations, since brain activity can differ between different persons. In this paper we discuss our findings on detecting eye blinks of one test subject and correlate eye blink frequency with the experienced level of stress. We also present our findings on mental calculations with open and closed eyes, and their effect on brain activity. This line of research may be very useful to classify stress inducing features and stress control of gameplayers.

There are numerous other applications where eye blink detection may be used to enhance stress monitoring. It also useful for the scientific EEG community since eye blink artifacts contaminate the EEG signal the most (Peterson, 1999). For our experiment we chose EEG as the technique to capture brain activity. Its detection technique is based on the electrochemical brain activity. It has excellent temporal resolution in contrast to blood flow techniques. such as fMRI and PET (Horlings, 2008). The high temporal resolution together with the low cost make EEG a great solution for our research.

In our experiment we acquire brain activity using EEG equipment, convert and remove artifacts using software, extract and select features characteristic for eye blinks and finally classify the signal, using the selected features as eye blinks in the signal (figure 1).

Two challenges have been identified for our work:

• Detecting eye blinks in EEG signal
• Isolating events to be able to link the eye blink frequency to the perceived level of stress.

For the detection of eye blinks we use techniques of the signal processing field to remove unwanted artifacts (like lateral eye movement which usually effects EEG nsors F7 and F8), background noise (which is captured using EEG sensors A1 and A2) and other noise. To isolate events we use a custom car driving simulation.

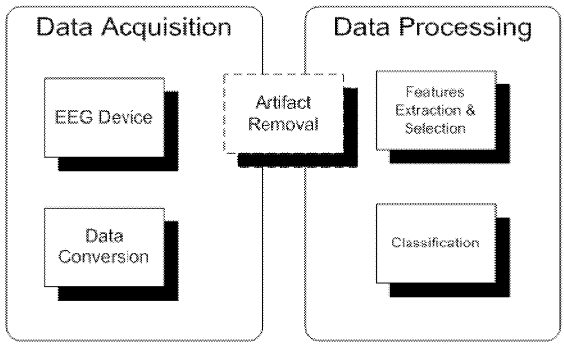


Figure 1: Schematic overview of the research method

1. Eye blinks

Eye-blinks are an often unwanted feature found in EEG measurements, due to the eye lid muscles' proximity to the posterior sensors Fp1 and Fp2 (Yoo et. al. 2007). The signals measured from the muscles have a magnitude 2 much greater than the signals from the brain, and as such they often occlude essential data. Although several methods are available for detection and removal of eye-blinks, their greater magnitude makes them more easily detectable than other features, both visually and analytically – they occur mostly in the 0.5-3 Hz range of the power spectrum (Manoilov 2006). This paper is outlined using the following structure. First we have a brief look at previous research in this subject. Then the set-up and tools are discussed. Following, the paper goes into the actual conducting of the experiment and present a summary of the collected data. Finally, we analyse the data, extract result and come to a conclusion.

RELATED WORK

A lot of research has been done on detecting eyeblinks using specific features of the data, such as:

Cross-Correlation (Yoo et.al. 2007); this method is capable of detecting and removing eye-blink artifacts through average and cross-correlation features of the independent EEG components,

Power spectrum analysis (Manoilov 2006); this method exploits the lower amplitude signature coming from the Fp1 en Fp2 sensors,

EMCP (Hoffman 2008) and ICA (Hoffman 2009) ; the EMCP method is based on regression while ICA is a blind source separation algorithm assuming statistically independent components.

EEG analysis (Dharmawan, Horlings, Rothkrantz 2006, 2008), the research was focused on detecting emotion during game playing.

TOOLS

To conduct the experiment we used the TruScan 32 EEG system from Deymed Diagnostics (see figure 2) with 19 electrodes placed according to the 10-20 placement standards (figure 3b). This solution from Deymed provides both the Brain Computer Interface as well as the capture and analysis software. We used Matlab and the EEG toolbox to further analyze these signals.

1. Hardware

For a full list of required hardware, see (Horlings, 2008).
The most important hardware components are listed below.

• EEG Cap, fitted with 19 electrodes, senses the brain activity,
• Earlobe electrodes, these measure the backgroundnoise,
• EEG Headbox, this box connects the cap with the computer.

2. Software

A. Data Acquisition

Deymed's TruScan Acquisition (TA) is used for the recording of the EEG signals. TA contains an overview of all electrodes and allows the test administrator to add markers and notes during a recording when significant events occur in the experiment.

B. Data analysis

Deymed's TruScan Explorer (TE) is used for loading the captured EEG data and do basic filtering and analysis. Matlab is used to perform statistical analysis on the data.

EXPERIMENT

A. Set-up of the experiment

In this experiment a test participant is required to drive a race car simulator while an EEG recording is made of his brain activity (figure 3 and figure 4). The race car simulator contains a number of predefined race tracks.

The test participant wears an EEG cap contains 19 electrodes. These electrodes are connected to the TA recording software through the headbox and a pc adapter. The software is operated by the operator, who in real-time adds markings to the recordings at moments of interest. This can for instance be when a billboard appears in the race track simulation, or when the participant crashes the car. During the analysis of the recorded EEG data, the appearance and subsequent cognitive processing of the billboard can be correlated with measured brain activity. Figure 3a shows a test participant in the experiment set-up.

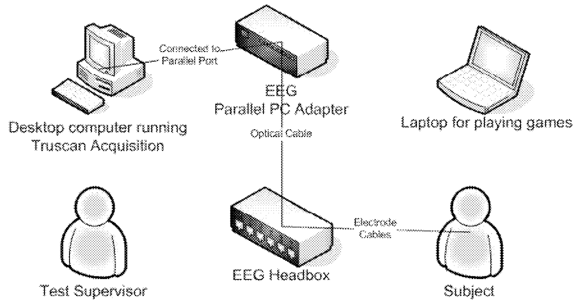
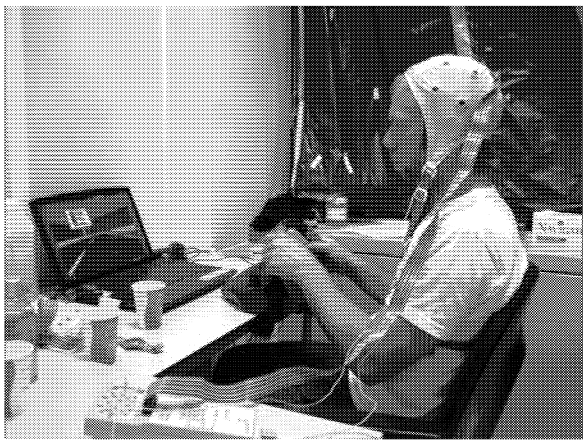
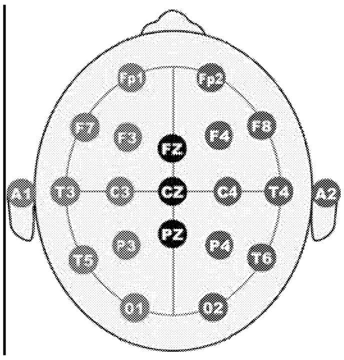


Figure 2: Setup for the equipment used for the setup in all experiments



(a)



(b)

Figure 3: The recording of an experiment in progress, with the participant wearing the TruScan 32 EEG cap (a) and the layout of the sensors (b)

Figure 4: Car driving simulator

B. Description of the conducted experiments

A number of experiments have been conducted, which can be divided into two groups. The first set of experiments (table I) consists of the participant driving on a track, either a 10 km long straight road, or three laps on a curved race track (figure 5), optionally with or without billboards (figure 6). There are two variables which are expected to influence the participant's performance and the resulting EEG recordings. The first variable indicates the type of track, straight or curved.

The second variable denotes the presence of billboards. Both tracks contain 10 billboards. These billboards are meant to distract the parti by either showing graphic pictures of car accidents, or, as in the case of our experiment, scarcely dressed females and shocking anti-smoking ads. Each track contained one billboard with a business ad, not containing any graphic content. On the straight road, the billboards are placed equidistantly, 100 meters apart, with the first billboard at 50 meters. At a speed of 70 km/h, billboards appear about every 50 seconds (table II). On this track, billboards can be sighted from 60 meters away (equivalent to about 30 seconds), and their contents can be distinguished from 25 meters. On the curved race track, the billboards are randomly placed, mostly near the more difficult sections of the track (figure 5, table II).

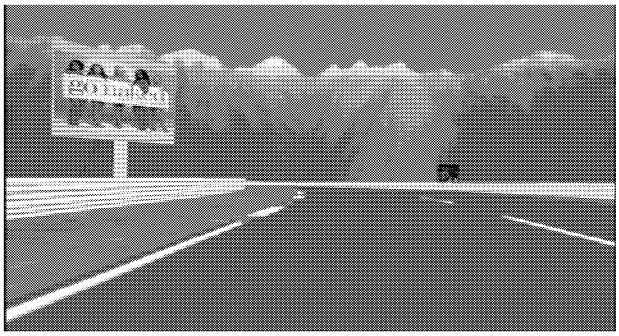


Figure 5: Typical scene from the curved race track with billboards

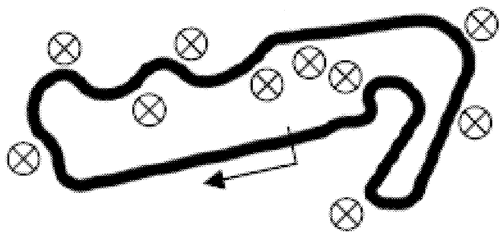


Figure 6: The curved race track driven by the participant. Markers indicate locations of the billboards, if enabled

Table 1: Experiments involving the participant in driving around a track

Number	Track	Billboards
1	Straight road Max. speed: 70 km/h Length: 10000 m Time: ~8m 36s	No
2		Yes
3	Race track Max. speed: 160 km/h Length: 4258m Time: ~1m50s	No
4		Yes

The second set of experiments (table III) required the participant to perform a few simple tasks. The EEG recordings from these experiments may offer additional insights to the recordings from the experiments that were mentioned previously. Experiment 5 required the test participant to drive on a straight racetrack.

The test administrator would give simple commands such as 'change lane' or 'weave between the left and right lanes', and mark the recordings when these commands were given. Experiments 6 and 7 did not require the test participant to control a racetrack simulator. The participant was asked to relax and perform a few basic multiplications (such as 23 X 15). This experiment was conducted twice, once with the eyes open (experiment 6), and again with the eyes closed (experiment 7).

Table 2: Placement of billboards

Number	Time (position)	Billboard
Straight road		
1	00:15 (50 m)	female(s)
2	01:05 (150 m)	female(s)
3	01:55 (250 m)	female(s)
4	02:50 (350 m)	female(s)
5	03:40 (450 m)	female(s)
6	04:30 (550 m)	female(s)
7	05:20 (650 m)	anti-smoking ad
8	06:10 (750 m)	business ad
9	07:05 (850 m)	female(s)
10	07:55 (950 m)	female(s)
Curved race track		
1	00:25	female(s)
2	00:34	anti-smoking ad
3	00:39	female(s)
4	00:44	female(s)
5	00:49	female(s)
6	00:57	anti-smoking ad
7	01:06	female(s)
8	01:15	female(s)
9	01:22	female(s)
10	01:38	business ad

Table 3: Experiments involving the participant performing simple tasks

Number	Duration	Track	Billboards	Description
5	1m 03s	Straight	No	The test participant was required to execute commands such as 'steer left', 'steer right', or 'change lanes'
6	1m 20s	None	None	With his eyes closed the test participant is asked to multiply two numbers
7	1m 39s	None	None	With his eyes open the test participant is asked to multiply two numbers

C. Data recorded during the experiments

Different features appear in the data that have been recorded during the experiment. The data is first filtered using a bandpass filter. Following previous research, we've used a high pass filter of 2 Hz and a low pass filter at 40 Hz (Horlings 2008). Using a high pass filter at 2 Hz makes the visual detection of the eye blinks much easier, while frequencies below this band are part of the Delta band and only occur in the brain during deep sleep (Horlings 2008). Frequencies above 40 Hz contain little to no activity, and are polluted with common interferences such as from the electrical net with AC currents at 50 or 60 Hz. For eye blink detection alone, the frequencies between 20 and 40 Hz are not relevant, but we have included them for spotting other features of brain activity presented in section 5.

The data from the first experiment is used as reference data (figure 7). The straight track required minimal corrective steering adjustments and the omission of billboards ensured no emotional responses were triggered. The steering corrections showed a temporarily increase in variance in the measured signals between sensors fp1-f7 and f7-t3 (steering to the right) and fp2-f8 and f8-t4 (steering to the left).

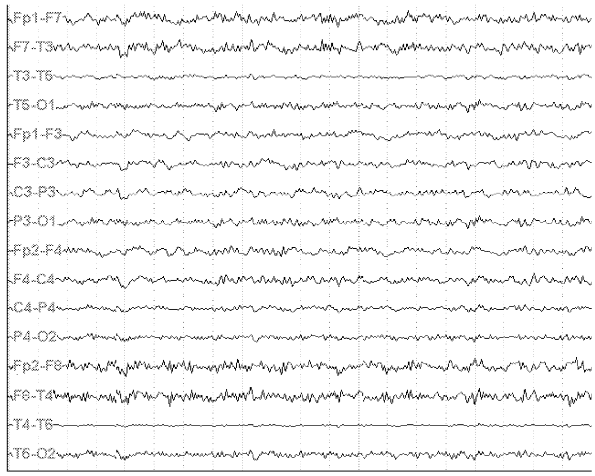


Figure 7: Typical EEG pattern when driving on a straight road, without any billboards (experiment 1)

Important features of this experiment are the eyeblinks, as their frequency is used to measure the perceived level of stress the participant is under. Figure 8 shows a two second recording with a single eye-blink occurrence (highlighted). The potential difference between sensors Fp1 and Fp2 and their neighbors is increased during the duration of the eye blink, which is typically between 200 and 400 ms (Yoo et al. 2007).

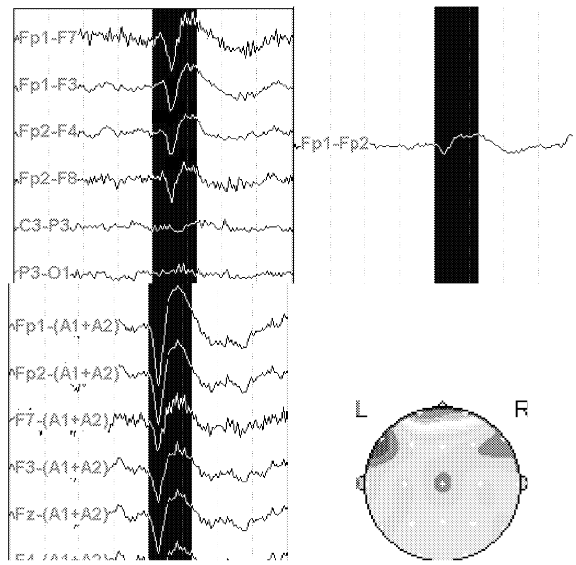


Figure 8: A two second recording with a single eye-blink highlighted, using longitudinal differences (a), traverse differences (b), and the earlobes as reference (c). Only the relevant channels are shown. Finally an amplitude map of this same moment (d).

The longitudinal differences (figure 8a) allow easy visual identification of the eye blinks as peaks on the differences between Fp1 and Fp2 and their surrounding electrodes.

The transverse differences (figure 8b) measures the potential differences between Fp1 and Fp2. Because both sensors will be triggered simultaneously during an eye blink, the eye blinks are barely noticeable. Using the earlobes as reference (figure 8c), such as the ear lobes, has the effect of eye blinks showing up on all channels, not just on Fp1 and Fp2. Even though eye blinks are easily spotted in this configuration, essential data on other channels may be masked.
The following tables list the occurrences of eye blinks while riding on the straight road. Table 4 shows the measurements for the straight track without any billboards. The first minute of this data was not usable do to distraction of the participant, and has been removed. The has been shifted such that the first eye blink occurs at 0 seconds.

Table 4: Eye blinks occurring while riding on the straight road without billboards

	Time				Time		
#	min:sec	sec,onds	Diff	#	min:sec	seconds	Diff
1	0:00	0	0	15	4:07	247	10
2	0:13	13	13	16	4:20	260	13
3	0:15	15	2	17	4:28	268	8
4	0:45	45	30	18	4:32	272	4
5	1:15	75	30	19	4:50	290	18
6	1:41	101	26	20	5:01	301	11
7	2:02	122	21	21	5:25	325	24
8	2:09	129	7	22	5:30	330	15
9	2:16	136	7	23	5:53	353	23
10	3:01	181	45	24	6:32	392	39
11	3:22	202	21	25	6:37	397	5
12	3:42	222	20	26	7:20	440	43
13	3:46	226	4	27	7:24	444	4
14	3:57	237	11	28	7:34	454	10

Table 5: Eye blinks occurring while riding on the straight road with billboards

	Time				Time		
#	min:sec	sec,onds	Diff	#	min:sec	seconds	Diff
1	0:00	0	0	38	3:32	212	1
2	0:03	3	3	39	3:34	214	2
3	0:16	16	13	40	3:35	215	1
4	0:18	18	2	41	3:38	218	3
5	0:26	26	8	42	3:43	223	5
6	0:41	41	15	43	3:48	228	5
7	0:44	44	3	44	3:53	233	5
8	0:47	47	3	45	3:58	238	5
9	0:49	49	2	46	4:00	240	2
10	0:53	53	4	47	4:12	252	12
11	0:56	56	3	48	4:20	260	8
12	1:01	61	5	49	4:34	274	14
13	1:05	65	4	50	4:42	282	8
14	1:11	71	6	51	4:49	289	7
15	1:21	81	10	52	4:50	290	1
16	1:24	84	3	53	5:16	316	26
17	1:32	92	8	54	5:18	318	2
18	1:34	94	2	55	5:21	321	3
19	1:39	99	5	56	5:24	324	3
20	1:40	100	1	57	5:28	328	4
21	1:46	106	6	58	5:32	332	4
22	1:47	107	1	59	5:41	341	9
23	1:54	114	7	60	5:50	350	9
24	1:58	118	4	61	5:52	352	2
25	2:03	123	5	62	5:57	357	5
26	2:09	129	6	63	6:02	362	5
27	2:18	138	9	64	6:08	368	6
28	2:20	140	2	65	6:17	377	9
29	2:35	155	15	66	6:24	384	7
30	2:36	156	1	67	6:32	392	8
31	2:40	160	4	68	6:38	398	6
32	2:42	162	2	69	7:01	421	23
33	2:50	170	8	70	7:06	426	5
34	2:54	174	4	71	7:23	443	17
35	3:06	186	12	72	7:41	461	18
36	3:22	202	16	73	8:00	480	19
37	3:31	211	9	74	8:03	483	3

Table 6: Eye blinks occurring while riding on the curved without billboards

	Time				Time		
#	min:sec	sec,onds	Diff	#	min:sec	seconds	Diff
1	0:00	0	0	24	4:05	245	3
2	0:35	35	35	25	4:06	246	1
3	0:36	36	1	26	4:08	248	2
4	1:09	69	33	27	4:12	252	4
5	1:21	81	12	28	4:30	270	18
6	1:50	110	29	29	4:41	281	11
7	1:51	111	1	30	4:42	282	1
8	2:11	131	20	31	4:43	283	1
9	2:13	133	2	32	4:47	287	4
10	2:14	134	1	33	5:40	340	53
11	2:16	136	2	34	5:57	357	17
12	2:21	141	5	35	5:58	358	1
13	2:45	165	24	36	5:59	359	1
14	2:46	166	1	37	6:00	360	1
15	3:06	186	20	38	6:01	361	1
16	3:08	188	2	39	6:02	362	1
17	3:09	189	1	40	6:03	363	1
18	3:24	204	15	41	6:04	364	1
19	3:40	220	16	42	6:06	366	2
20	3:42	222	2	43	6:07	367	1
21	3:57	237	15	44	6:08	368	1
22	3:58	238	1	45	6:09	369	1
23	4:02	242	4	46	6:12	372	3

Table 7: Eye blinks occurring while riding on the curved with billboards

	Time				Time		
#	min:sec	sec,onds	Diff	#	min:sec	seconds	Diff
1	0:00	0	0	14	2:55	175	2
2	0:09	9	9	15	3:28	208	33
3	1:01	61	52	16	3:30	210	2
4	1:48	108	47	17	3:47	227	17
5	1:57	117	9	18	3:48	228	1
6	2:16	136	19	19	4:01	241	13
7	2:28	148	12	20	4:39	279	38
8	2:29	149	1	21	4:40	280	1
9	2:30	150	1	22	4:45	285	5
10	2:41	161	11	23	5:46	346	61
11	2:43	163	2	24	5:47	347	1
12	2:47	167	4	25	5:49	349	2
13	2:53	173	6				

Table 8: Crashes on the curved track

Without billboards			With billboards		
#	min:sec	sec,onds	#	min:sec	seconds
1	0:33	33	1	2:28	212
2	1:49	109	2	2:41	214
3	2:42	162	3	4:24	215
4	3:55	235	4	4:40	218
5	4:26	266	5	5:46	223
6	4:40	280			
7	5:54	654			

ANALYSIS

A. Eye blink frequency in stressful situations

We first analyzed basic statistical properties. Figure 8 shows the distributions of the time between the eye blinks. The graph for the curved race track without billboards (figure 9c) has been clipped. The last 20 seconds of the data showed continuous blinking. Although this has been removed from the distribution, we will include this data in the remainder of our analysis.
All distributions show properties of the Gamma distribution, which could be expected (Dekking et al 2005). It is

immediately obvious that the presence of billboards has an effect on the emotional state (figures 9a and b). The mean time between two eye blinks is much shorter, which is to be expected given many more eye blinks in the same amount of time.

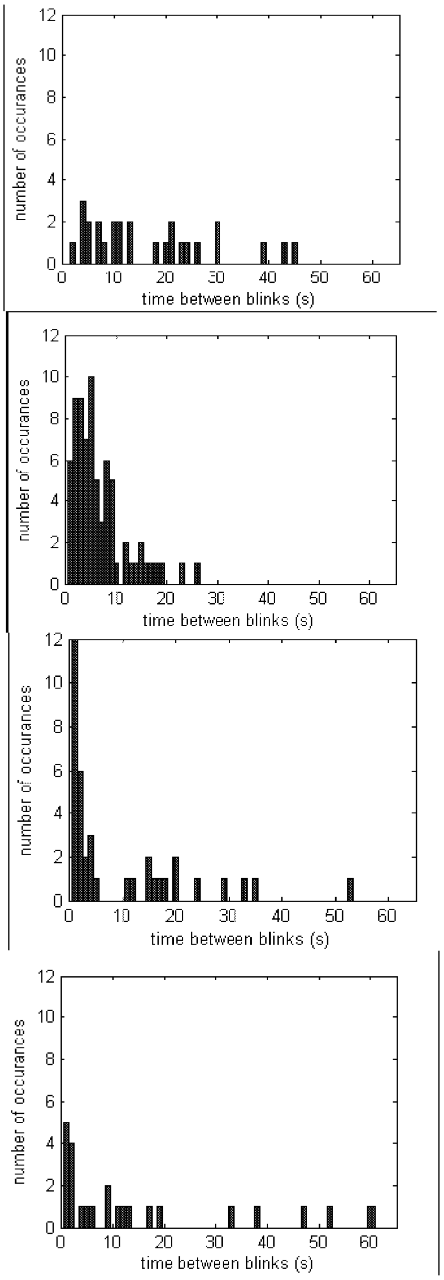
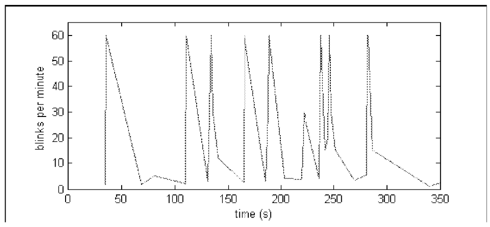


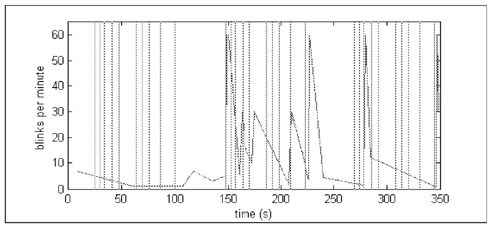
Figure 9: The distribution of eye blink intervals (seconds) for each of the driving simulations; straight road, no billboards (a), straight road, with billboards (b), curvy race track, no billboards (c) and curvy race track with billboards (d)

The same does not happen for the curvy race track, though. The distributions are similar, and in fact the track without billboards shows a higher count of blinks, and a lower mean time between blinks. This can only partly be explained to the stress experienced of having to steer the vehicle, and control the throttle to stay on the track.

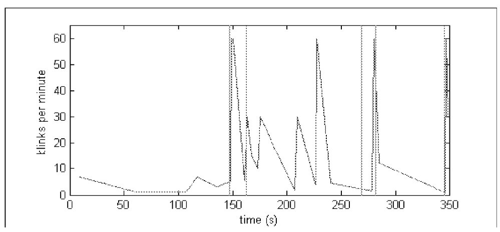
While on the straight road the presence of emotion stimulating billboards has an obvious effect, there is no significant difference in the perceived emotions on the curvy race track. To support this notion, we have marked both the billboards and crashes onto the eye blink data. If we plot the billboards on the data (figure 10b), there appears no connection between the location of a billboard and the perceived emotion. But if we mark the crashes (figure 10c), we see an immediate increase in eye blink frequency after a crash, indicating a strong correlation between the two. This shows that in fact the crash, even though only simulated, causes an immediate emotional response. This still leaves the issue of the higher eye blink on the curvy track without billboards as opposed to the one with billboards. This is probably due to the fact that more crashes occurred during this run, as well as the fact that the participant still had to adapt to the curvy track, and was more emotionally tense when driving the first few laps.



(a)



(b)



(c)

Figure 10: Projected eye blinks per minute for the curvy race track without billboards (a), and with billboards (b and c). The billboards are shown as markers in (b), the crashes are shown as markers in (c)

B. Brain activity under mental load

Figure 11 shows an EEG pattern of the participant during experiment 3, while passing through a sharp turn in the race track. The amount of variation in the EEG signals seems to be related to the psychophysical load of the steering task at

the moment. Sharp curves in the racetrack require more cognitive processing and exertion of physical control than gentle ones. For instance gentle curves can be completed without potentially becoming uncontrollable. Some of the curves in the race track show activity such as in figure 12, while others do not show any increase in brain activity. Another noticeable situation is the EEG patternthat emerges when the participant loses control over the race car and it crashes into the sidewall of the track. The EEG pattern then reflects all the psychophysical activity that must be done in order to get back in control of the race car.
The second set of experiments that were conducted also revealed some EEG patterns of interest. From figure 13 and 14 the difference is visible between the participant's brain activity when his eyes are open and when they are closed.

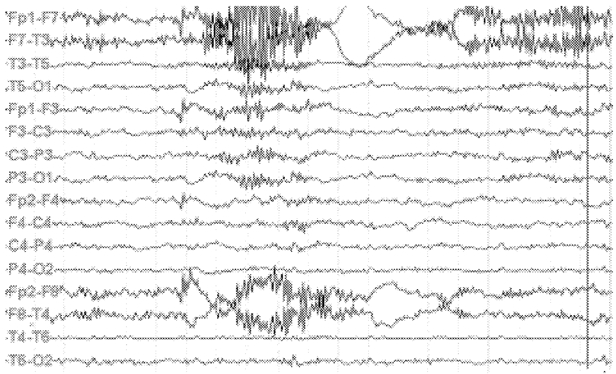


Figure 11: EEG pattern when driving through a curve that required relatively much control adjustments

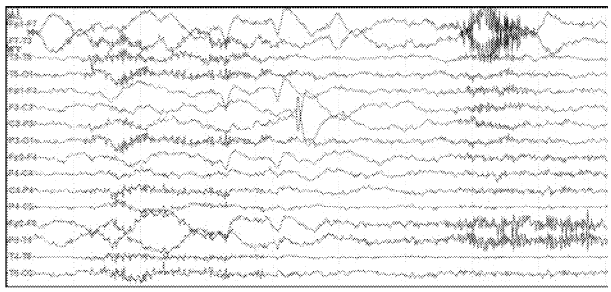


Figure 12: A 10 second EEG clip showing brain activity while the car becomes uncontrollable

Figure 13: EEG pattern from experiment 7 – the participant has his eyes open and is asked to calculate 90 X 6

Figure 14: EEG pattern from experiment 8 – the participant has his eyes closed and is asked to calculate 19 X 8

In both cases the participant was asked to perform relatively simple calculations, which were done correctly. However, it appears that the brain is much busier when the eyes are opened, possibly because it is engaged in subconsciously processing what the eyes see, even when the participant's attention is not focused on his surroundings. It is interesting to notice that the occipital lobe (responsible for vision) activates when the participants eyes opened briefly (figure 15).
Another observation was the activation of the left frontal lobe. Earlier studies show that exact math is mostly done in the left frontal part of the brain (Spelke et al. 1999). Figure 16 shows a time lapse of 4 amplitude maps 8ms apart.

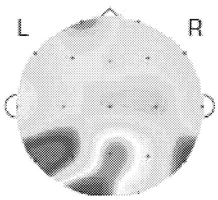


Figure 15: Brain activity after opening the eyes, clearly showing activity in the occipital lobe

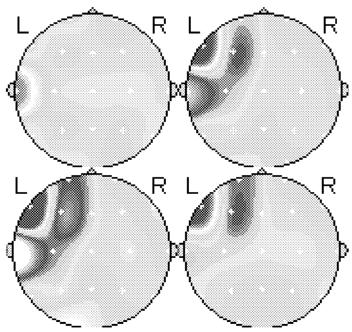


Figure 16: Brain activity during performing mathematical exercises, clearly showing activity in the left frontal lobe. Each map is taken 8 ms apart

RESULTS

There seems to be an obvious connection between eye blink frequency and the perceived level of stress. Both artificially triggered emotional responses by using billboards, and more natural emotional responses occurring after crashing the car in the drive simulator cause a temporary increase in the eye blink frequency. Unfortunately the results from the classification of emotions from the recorded EEG signals cannot be strongly correlated with the data. The participants were not interviewed or otherwise asked to state which emotions they perceived during specific event of the experiment. Additionally, short dummy sessions could be held on the straight track to make the participant more comfortable the experiment.

In the second set of experiments we noticed that specific brain areas were being activated after certain events. The occipital lobe was highly active when opening the eyes and the frontal lobe was highly active when doing the mental calculation. Although this is expected according to other studies (ie. Spelke and Dehaene), this reseach is not able to connect stated brain areas with mentioned events. This would require a different experiment set-up. A weakness of using EEG signals for combined eye blink and brain activity detection is that both occlude each other. Firstly, only relatively strong electric potential at the outer edge of the scalp only are recorded. The origins of the emotional brain however are not limited to the outer edge alone. Secondly, the generated electrical potential from brain activity, and the electrical potential from muscle activity from the eye lids tend to occlude each other.

To remedy these problems, we would recommend using separate eye lid sensors. This allows much more accurate eye blink detection and removal of these artifacts from the EEG data.

CONCLUSION

Our results show that there is a strong correlation between eye blink frequency and emotional stress. This was even more apparent during more confronting situations, such as the simulated car crashes Although the temporal increase in eye blink frequency can already be used as a measure of stress, our method is not accurate enough to be used in commercial applications. Further isolating the eye blink from the EEG signal using other features and possible enhanced stress detection using additional sensors, for example attached to the eye lids, are interesting research topics. The detection of eye blinks in an EEG signal is easily done visually, using the longitudal differences of sensors Fp1 and Fp2, presenting eye blinks as unique peaks. When displaying the amplitude map, a clear active area of the prefrontal cortex is shown. Automatic detection of eye blinks using these two characteristics possible. During the analysis of the mental calculation we noticed an active left frontal lobe. This confirms the theory of increased brain activity in the left frontal lobe during mental mathematical processing, as stated by Spelke and Dehaene. We further noticed significant less variation in the EEG signal when the subject's eyes were closed and detected a spike in the occipital lobe when opening the eyes, indicating increased visual processing. This confirms that brain activity is heavily influenced by visual information. We noticed no correlation of math performance and eyes closed or open.

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SETTING UP A VIRTUAL FACTORY BASED ON 3D INTERNET PLATFORMS

Stefan Seitz
Marco Hermann
Daniel-Percy Wimpff
Department of Coporate Logistics
Fraunhofer Institute for Manufacturing Engineering and Automatisation
Nobelstrasse 12
70563 Stuttgart, Germany
E-mail: Stefan.Seitz@ipa.fraunhofer.de

KEYWORDS

Production Simulation, Game-based, Second Life, Virtual World, Serious Games

ABSTRACT

In the past, industry set the pace for the “Digital Factory”, where digital tools are used to optimize production. Meanwhile, the growing gaming industry has developed highly sophisticated applications imitating reality for more and more demanding consumers. So-called 3D-internet worlds, despite being a little outdated in a technical sense, now offer new and exciting possibilities for professional use. While being created for social interaction, they might offer interesting advantages for simulation and the training of future employees. These low-cost platforms enable cross-border communication and the visualization of operational work anytime and anywhere. But they also allow setting up entire plant simulations. Combining these capabilities, the platforms can be easily enhanced to provide a particular, collaborative training area for learning serious topics in a playful way. To identify the drawbacks and opportunities of this technology, Fraunhofer IPA created a “Learning Factory” based on the virtual world of ”Second Life“called ”Factory of eMotions”.

INTRODUCTION

This paper explores the possibilities of using virtual 3D internet platforms for the cooperative simulation of production scenarios to build a virtual factory as an integrated, specific training environment . The state of the art in training tools is represented by generic proprietary tools. These tools, however, do not provide any opportunities to reflect specific plant conditions, nor do they enable collaborative work; in addition, they are mostly 2D and expensive.

The game industry on the other hand has developed an astonishing set of different technologies which are easy and, at least for some platforms, free to use. Also, in the case of online platforms like “Second Life”, the communication capabilities are further developed than with most commercial software. Therefore, the research project “Factory of eMotions” uses the gaming platform “Second Life” to develop a fully simulated “Learning Factory” implementing real-life factory concepts ranging from order management to machines and carriers on the shop floor. Fraunhofer IPA also integrated voice control to directly interact with a number of components. The aim is to learn serious production and logistics topics by simply playing a game.

STATE OF THE ART

Simulation and the “Digital Factory”

For decades, the Fraunhofer IPA has supported multiple activities known by the term „Digital Factory“, which intend to optimize real-life production using digital tools (Westkämper et al. 2001). Most of these solutions are proprietary software tools which are only slowly penetrating the market due to high purchase costs and the need for specialized programming knowledge. So far, these solutions have been widely used only in large enterprises, whereas small and medium-sized companies shrink from such barriers. This finding is confirmed by a study of the Fraunhofer IPA on barriers to the use of simulation in SMEs: A survey among managing directors of SMEs found almost 50% of them confirming that the high purchase and licensing costs and another 30% that the lack of know-how are the reasons for not having yet introduced digital tools (Bierschenk et al. 2005). Another barrier is that the use of professional applications to create simulation models requires a high skill level. According to Dangelmeier ”only experienced and well-trained experts are able to operate these programs” (Dangelmaier et al. 2005).

3D Internet Worlds

In the last years, a number of 3D Internet worlds has evolved that provide free access for anyone to visually pleasing simulation in real time. The possibilities offered by these technologies are staggering. Some authors even consider them as representing a“frontier in social computing with critical implications for business, education, social sciences, technological sciences, and our society at large“(Messinger et al. 2009). These worlds originally catered for the needs of private individuals. Their focus was mainly on the communication among users and on the graphical representation of creative ideas. Using a second ego, the so-called avatar, anyone can enter the virtual world via Internet. In 2009, an average of 70,000 persons all over the world is using the platform of Second Life at the same time. A total of 1.4 million of different users were registered in the last 60 days. Its high number of users, its technical flexibility as well as its reliability make Second Life, in particular, a subject of interest for institutions worldwide.

Professional use of this technology is made by large companies and research and educational institutions in two main application areas. On the one hand, it is used for internal communication platforms to coordinate international teams, for instance at Intel or Northrop Grumman. On the other hand, platforms are used as a basis for interactive learning and demonstration environments for research and teaching. As examples may not only serve the Universities of Stanford and Harvard, but also research institutions such as NASA (Messinger et al. 2009).
Although the open architecture and the excellent accessibility provide great opportunities, few attempts have been made to exploit the graphical and simulation capabilities of the 3D Internet worlds for the areas of production and logistics.
According to Bergbauer, the benefit that the use of virtual worlds entails is the capacity to model complex structures and processes and derive decisions from these models. They also facilitate the identification of errors and the optimization of processes (Bergbauer 2002, p. 27 – 46).

Voice Control

Another strong advantage of virtual worlds is the easy integration of other web-based technologies, e.g. the Voice Control API (VCA) developed by the Fraunhofer IPA and Sikom Software Gmbh. Today's voice recognition systems are user-independent systems that process complete spoken sentences (Natural Language Processing, NLP) based on grammars that have a defined vocabulary. The external communication between the voice recognition system and the business application is normally established via VoiceXML. The VoiceXML documents describe the dialog flow and can be integrated by the application via web server. User input is processed through an integrated Automated Speech Recognition (ASR) system. To output synthesized speech, the VoiceXML browser utilizes a Text-To-Speech (TTS) system [WEST08, p. 52 – 81].
This architecture, though established as industrial standard, modularized and scalable, has severe drawbacks with regard to integration:

- VoiceXML supports basic control structures known from programming languages, but the eXtended Markup Language (XML) it is based on is not suitable as syntax for a programming language
- VoiceXML does not support modern concepts of software design (like object-orientation)
- the application (in this case "Second Life" is required to implement or integrate a web server to deliver VoiceXML documents and receive user input

To circumvent these disadvantages and gain granular control over the voice recognition system, Fraunhofer IPA developed the web service »Voice Control API (VCA)«. It wraps the generation and processing of VoiceXML. As SOAP web service it offers a simple, transparent and platform-independent programming interface.
This is the reason why Fraunhofer IPA decided to include the VCA system as a demonstration application for the communication facilities of the virtual factory. After a detailed comparison of the various 3D worlds, a first prototype of virtual factory simulation was built on the Second Life platform.

APPROACH

The strategy of the „Factory of eMotions“ is based on the visions of a factory of the future defined by Professor Westkämper in 2008 (Westkämper et al. 2008) and by the industry requirements defined in Manufuture-DE (Manufuture 2008) in the topics of "Digital Product Development" and "Digital Factory". The goals of the project are twofold. Figure 1 illustrates the basic project idea.

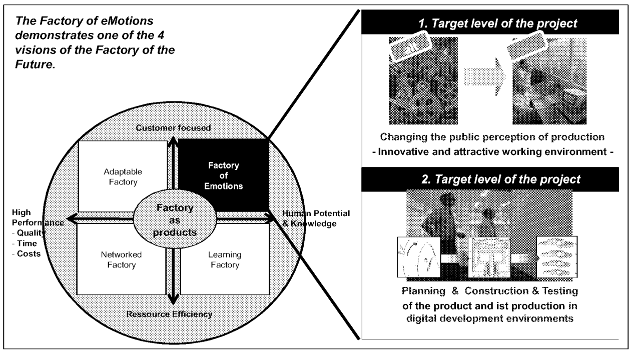

Figure 1: Research focus "Factory of eMotions"

On the one hand, the intention of the „Factory of eMotions“ is to give the general public an understanding of production and work in a factory as an innovative environment. On the other hand, it aims to lay the foundation for the "Learning Factory" in a modern, innovative environment.
To accomplish the first goal, interactive training elements are used to make the user familiar with innovative topics from production and logistics. The interaction takes place at four levels:

Table 1: Levels of interaction in the Factory of eMotions

Product-related interaction: Product configuration and „test runs“	Interaction on the shop floor: activities in the production process	Elements of edutainment: Logistical training islands	Voice recognition: Interaction via phone
Variety of product components	Robot control	Customer order decoupling point	Quality inspection via speech
Self-configured "take away-product"	Interaction in assembly	JIS/JIT supply	Movements in assembly via speech
	Building your own small production parts	Kanban principle	

To accomplish the second goal, a whole Factory has to be built and all processes, from order management to the collaboration of machines on the shop floor, need to be simulated. For a greater variability in the creation of specific plant environments, programming focuses on the generic implementation of all „Factory of eMotions“ elements to accomplish very flexible individual objects. Similar to the building blocks of a traditional material flow simulation, the developed framework and the scripts of the individual elements can be used to represent any given production scenario. The employed platform of Second Life so far does not support the visual representation of material and information flows. Based on the basic functions of the Scripting language, a complete framework of production-specific components has been developed. The following Figure 2 shows the main building blocks on a concrete level.

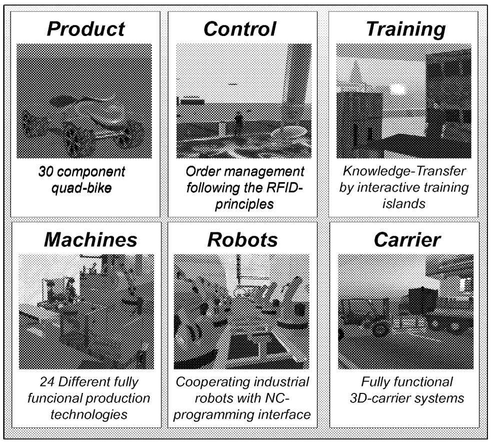

Figure 2: Elements of the "Factory of eMotions"

The overall outcome of the project has been a virtual „island“ with a fully simulated virtual factory called “Factory of eMotions”. . With the created building blocks it is possible to implement scenarios for production simulation as well as for future interactive seminars and trainings.

BUILDING THE VIRTUAL FACTORY

The basic idea to use 3D Internet worlds for production purposes evolved in 2006. The thought behind it is to exploit the progress in the strongly growing field of computer games for the field of Advanced Industrial Engineering. The „Factory of eMotions“ shall create a complete picture of an operational factory. This is why the design of the whole virtual factory is based on the principles of factory and logistics planning. The approach is divided into three phases:

Phase 1: Planning

1.1 Types of factories

The first step is to fill the term „Factory of Emotions“ with meaning. The emotional identification with a subject in psychology is a key element to foster intrinsic motivation, i.e. to be self-motivated and directly responsible for achieving a certain objective. Transferred to the world of business, it becomes a vital competitive factor. In the first step, identification with a business is connected to a concrete product. For this reason, each user is enabled to create his/her own individual vehicle and trace it from „cradle to grave“ throughout the production process. In the second step, this is accomplished by letting them perform an interesting and demanding task. In the virtual factory, each user can actively intervene and influence processes. In the third step, emotional attachment is achieved by providing an attractive work environment. „Beautiful“ shapes as well as clarity and brightness will improve the work atmosphere. Graphical elements that generate positive associations are used in the same way, for instance renewable energy sources.

1.2 Product selection

The product of the „Factory of eMotions“ must be simple to manufacture but sufficiently complex to represent plenty of issues in a reasonable way. Moreover, it should make it easy for the user to identify with the product, while producing an added value even at a virtual level and providing a link to the topics dealt with by the Fraunhofer Society. This suggested the production of a virtual vehicle. For manufacturing reasons a four-wheeled motorcycle was chosen, the so-called quad bike.

1.3 Definition of the factory elements to be realized

To represent a complete picture of a real factory, it is necessary to define the key issues of a „Factory of Emotions“. The ideas that evolve can be divided into the fields of product, logistics, production technology, infrastructure, organization, staff and environment. Aspects such as the attractive design of the working environment, efficiency of resources and energy use, representation of corporate management and production control, integration of the factory into the social environment, as well as „enjoyment of work “ are defined as key elements.

1.4 Identification of individual knowledge content

Within the above-mentioned fields, the topics to be dealt with are specified with a view to the „ emotional attachment“ of the user. This leads, for instance, to the idea of an ergonomic „floating chair“ as a manufacturing aid that can be operated by the user. The basic control principles and levels, e.g. PPC system or Kanban, are also determined for demonstration.

Phase 2: Factory and Logistics Planning

2.1 Design of the production process

Starting from the 30 components of the product structure, the production process needed for manufacturing the product is defined. It is divided into a non-customer specific process manufacturing the frame and the chassis and into a customer-specific process manufacturing the body and final assembly.

2.2 Development of the land use plan

Parallel and closely connected to the planning of the production process is the creation of a land use plan for the Fraunhofer IPA island. An island is the virtual representation of a dedicated server in Second Life. A total of 64,000 m² of land can be built on. Approximately 25.000 m² of the latter are envisaged as floor area of the new factory. Additional areas are planned for delivering material to the factory (street network and suppliers) and a special area for a so-called „sandbox“, i.e. an area for testing the configuration of new production facilities.

2.3 Factory layout planning

The last planning step is the creation of a factory layout to specify the production process and the land use plan. The physical layout of the exact production process is defined and several architectural solutions are proposed. The finger-shaped production layout chosen makes it possible to deliver directly to the main assembly line and facilitates the expansion of the required floor area without jeopardizing material supply. Figure 3 shows the planned layout.

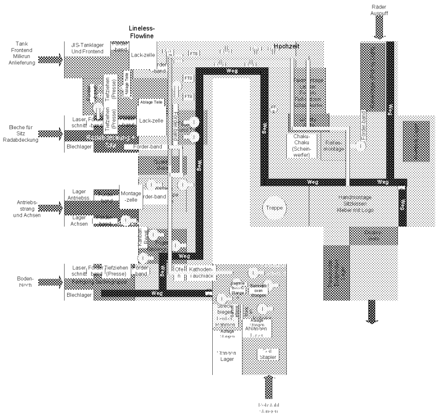

Figure 3: Layout of the virtual factory

In parallel to the actual production line, the training content and slide shows are designed on the second floor. The transparent design of the entire factory enables the user to keep track of the production process and the associated training content.

Phase 3: Implementation

3.1 Implementing the factory layout and graphical design of the „island"

Before implementation can actually start, the virtual building plot must be prepared for use and the empty shell of the factory must be created. The focus here is on putting the draft layout into practice with as simple and as few objects as possible.

3.2 Development and implementation of generic factory building blocks in Second Life

The LindenLabs Scripting Language (LSL) offered by the platform of Second Life is an in-world programming language. Based on process planning, the key functions of the individual building blocks are identified. All kinds of material transformation and movement through the machines can be represented by four basic principles: move, create, transform and delete.

These basic functions have been programmed to be accessible by a graphical interface so that no programming knowledge is required to execute them. In addition, a graphical method is used, called „Drag&Snap", for connecting predecessors and successors in a production chain. This is done by moving colored sensors on top of each other. The so-called „root" object contains the complete logic of the machine.

Figure 4 shows a screenshot of a draw bender to exemplify the structure of the elements.

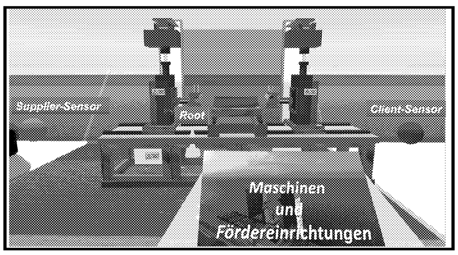

Figure 4: Example of the developed machines

3.3 Implementation of the control logic

To enable the linking of the generic factory components, it is necessary to use control principles that are similar to a real PPC system. This way, the production process can be reconfigured without needing to adjust the control node of all building blocks. The control logic of the „Factory of eMotions" follows the principles of the combined use of RFID and Kanban in a real factory. When the carrier gets a production order, an additional order control object is generated and linked to the order. This order control object is visually represented by a colored ball and contains the complete product and process description in coded form. In other words, the „Factory of eMotions" uses virtual objects to visualize the information flow as in a funnel model.

When the carrier arrives at a so-called "waypoint", the order information is transferred to the attached machines. These procure the necessary production information for the required product. After one process is finished, product and order information (as with a RFID tag) are transmitted to the next process.

Figure 6 illustrates the operational principles of the developed control framework.

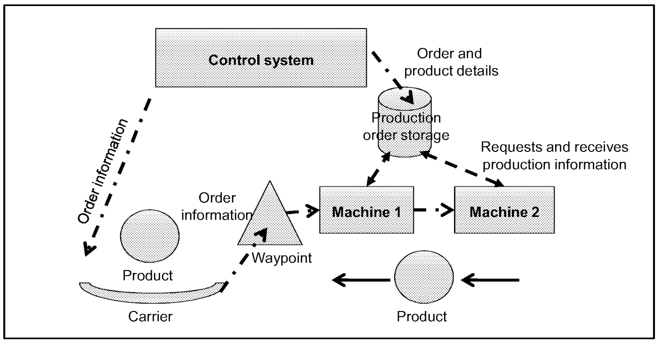

Figure 5: Control Framework

3.4 Integration with other ICT-systems

The last implementation step is about integrating other systems into the „Factory of eMotions". Speech recognition as researched by the Department for Quality Management makes it possible to control many elements by speech input via phone. For example, a virtual "Care-o-Bot", i.e. a service robot physically developed by the Fraunhofer IPA, enables a fascinating scenario. Integrating the virtual robot with its real-life counterpart enables the thirsty visitor to order refreshments in the virtual factory, which only a few seconds later will be delivered by the real-life counterpart. The order can be placed by phone and is processed in the VCA modul, which, besides the physical robot, is the second system integrated into the factory.

Implementing a VoiceXML server within the Second Life development environment based on the Linden Scripting Language (LSL) is unfeasible, since LSL does not support server sockets.

This prevents the integration of interactive voice dialogs based on the VoiceXML-architecture. Here is where the Voice Control API (VCA, figure 7) comes in.

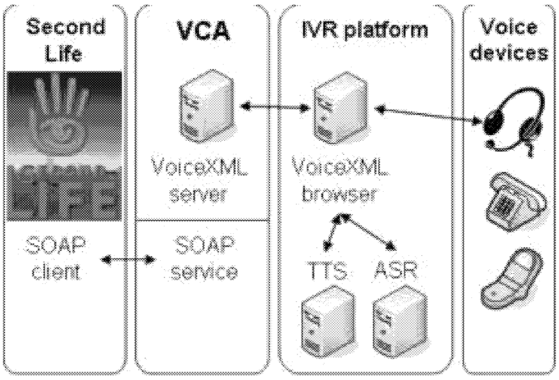

Figure 6: Voice Control API service

The VCA service offers a small set of functions as a SOAP web service that can be consumed by applications to gain granular control over voice interaction. The VCA service encapsulates the generation of VoiceXML and the communication with the IVR system. Each call to the VCA service will render a single VoiceXML document from a template to populate it with parameters and transfer it to the IVR system for execution. User input is returned to the application as a SOAP response [IPA08].

This SOAP response is processed in Second Life as a HTTP request. That way the VCA service enables developers to rapidly build voice interfaces for user interaction with objects in the virtual factory. Second Life has a built-in voice chat, but the signal quality it supports stays potentially below the requirements of voice recognition software. Instead of using the voice channels of Second Life, end-user devices like VoIP clients or PSTN phones are connected directly to the IVR system to achieve the desired quality of service. For example, to interact with a virtual service robot, the user dials in to a specific phone number that connects him to the robot in Second Life. A set of voice commands then allows controlling the robot.

This „gimmickry" for the general public highlights the strength of the platform when applied to industrial production. The opportunity to rapidly display new content in a visually appealing style allows for new ways of communicating via Internet, which could cut costs at many places in a business while speeding up processes and making them more efficient.

CONCLUSION

The successful implementation of the "Factory of eMotions" demonstrates the capacity of 3D internet platforms to simulate production and logistics scenarios. Moreover, they offer an excellent platform for the demonstration of new ideas and concepts. The widespread use in research and enterprises is only limited by the necessary programming effort to achieve realistic simulation results.

Building on the components developed in this research project, future application should be easy to implement.

The described methodology of building production scenarios can be adapted to other kinds and purposes of logistic and production simulation. Easily accessible and free to use virtual worlds might represent an important step towards a more widespread use of digital tools in enterprises.

The demonstrated integration with the voice recognition system can be transferred to other enterprise ICT systems. This allows for a seamless merging of virtual and real world. The simple integration achieved in this project demonstrates the powerful capabilities of both "Second Life" and the VCA.

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BIOGRAPHY

STEFAN SEITZ was born in Ostfildern-Ruit, Germany and went to the University of Ilmenau, where he studied Industrial Engineering and obtained his degree in 2005. As a senior researcher he has been working at the Fraunhofer IPA in the department of corporate logistics since 2007 and is specialized in digital tools for production optimization.

MARCO HERMANN was born in Günzburg, Germany and went to the University of Applied Sciences Ulm, where he studied Industrial Engineering and obtained his degree in 2008. He has been working at the Fraunhofer IPA in the department of corporate logistics since 2009.

DANIEL-PERCY WIMPFF was born in Ostfildern-Ruit, Germany and went to the "Akademie für Datenverarbeitung" in Böblingen, where he studied computer science and obtained his degree in 1998. After founding a small new economy company, he started working at the Fraunhofer IPA in the department of Product and Quality Management in 2007.

MODULAR TECHNOLOGY IN THE GENERATION OF LARGE VIRTUAL ENVIRONMENTS

Carlota Tovar
Ginés Jesús Jimena
Jose María Cabanellas
CITEF Research Centre on Railway Technologies
Universidad Politécnica de Madrid.
José Gutierrez Abascal 2. 28006 Madrid,
Spain
E-mail: ctovar@etsii.upm.es;citef-gjimena@etsii.upm.es ;jmcabanellas@etsii.upm.es

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methodology;3d-scalability;shaders;modularity;virtual environments.

ABSTRACT

This paper presents the latest research and development in modular technology. Modular technology is a constructive methodology intended for the creation of large virtual environments for serious games: terrain driving simulators. This technology uses a set of guidelines of the environment as a starting point for its designs and then, taking these, it generates the surrounding environment using the assembly and repetition of small modules. In this way, one of the basic tools for resource optimisation is exploited: instantiation. Calculating the number and optimum geometric design of the modules as well as the variety of their families will be decisive in obtaining the realism and refresh speed required.
On the other hand, in line with the latest trend, which is to redirect the largest possible share of graphical calculation to the GPU to lighten the load on the CPU as far as possible, as this is slower and less suited to graphic calculation, modular technology makes use of shaders. By programming shaders the number of geographical entities in the environment can be substantially reduced and their diversity and flexibility increased. This can be achieved by applying a series of geometric transformations to the modules. There are many benefits to be had from this form of generation: savings in scene size, load time and resource requirements, a greater flexibility and clarity of the scene graph and a considerably increased capability to update the environment.

INTRODUCTION

The use of game technologies in the generation of virtual driving simulators is a strongly established procedure. “Serious games” is the term coined to define a new niche (Zyda 2005), where game tecnologies are used with purposes that are not the entertainment. Movies, education, defense, arquitecture, training and simulation, city planning and medicine, are some of the industries using games technologies (Smith 2007).
Modular technology is a constructive methodology designed to create the environments of the virtual driving simulators of CITEF. What is understood by the constructive methodology of a virtual environment is the set of procedures that allow interpreting, processing, analysing, modelling, optimising and virtually displaying some very specific initial information.
A series of key points need to be borne in mind when choosing a constructive methodology: number of human resources , hardware , type of application and its ultimate purpose .
Modular technology has arisen from a need for a methodology that will:

- Work with a small number of human resources.
- With a PC and in general with hardware that does not always need to be the latest.
- Generate large virtual environments for virtual displays that are durable over time in which the user can drive a terrain vehicle over a series of pre-defined paths.

The first two points required a methodology that would minimise modelling tasks while still being flexible, so that it would be able to make the most of the latest advances in hardware, but at the same time remain effective when the available resources were not the most up-to-date ones. That is, it should minimise CPU consumption and the storage memory required for the geometries of the environment and be able to make the most of the latest advances in GPUs but without the foregoing being a requirement for it to function properly.
The third point involved other additional requirements:

- The driver’s proximity to their environment demanded maximum realism in the surroundings of the driving paths.
- For driving to be realistic, high refresh speeds were required.
- For the user to be able to launch different scenes easily and efficiently, loading times needed to be minimised.
- For the user to be able to design new environments easily, they needed to be easy to generate and edit.

On the other hand, these displays had a set of features that could facilitate their generation:

- Knowing the driving paths allows setting the distance at which the different elements will be observed, thereby enabling the optimum parameters of the levels of detail to be defined in pre-load time: the cut-off distances and polygon load for each level of detail.

•	The high driving speeds through the environment as well as the user's priority to drive correctly make it difficult to perceive this environment (Hitchner, 1993).
•	The repeatability of many elements of the environment linked to the low perception of them had by the user enables the benefits of instantiation to be exploited.
Taking into account all these points, modular technology looks for a solution looking into game technologies.

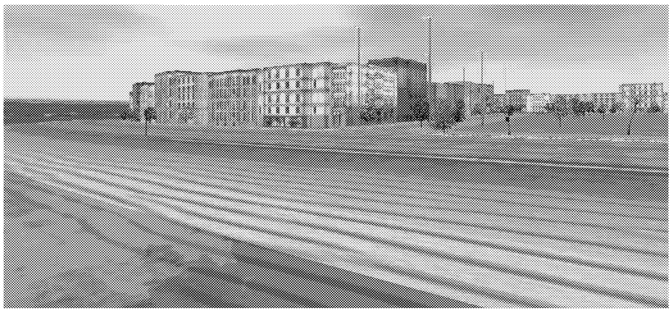

Figure 1. Example of a virtual environment generated with the modular technology

METHODOLOGIES FOR GENERATING LARGE VIRTUAL ENVIRONMENTS

Although it is difficult to compile a taxonomy of the methodologies used for constructing large virtual environments, modular technology differentiates two possible approaches:

- o **Tile-based methodology**, is characterised by its seeking the use of repetitive patterns as the basis of its designs to generate an environment by assembling and repeating a finite number of modules generated in pre-load time. This methodology usually goes hand-in-hand with the use of a system of discrete levels of detail. The most usual geometric shapes for generating these tiles are the rectangle, the circle, the hexagon and the diamond shape. The purpose of the two latter is to provide a greater feeling of depth. These tiles are placed adjacently to one another as the following figures show, completely filling the 2D space.

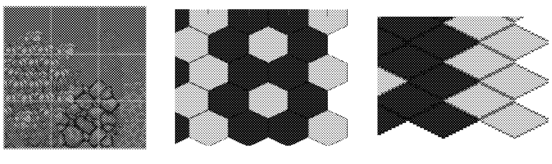

Figure 2. Examples of tiles

Most video games generated with this methodology are 2D games, such as *Age of Wonders*. Two of the best-known 3D games using this methodology are *Simcity*, and *Neverwinter Nights*. Their main feature is that they define the scene by using tiles that form part of what is known as a tileset. A tileset is nothing more than a set of tiles that follow a similar theme. For example, the City tileset can include tiles of pubs, inns…and other elements to be found in a city. The main aim of this methodology is to cut memory consumption, reduce modelling tasks. The level of detail of these scenes, however, plays a secondary role in fulfilling the objectives of the game, which means that realism is not a decisive factor when generating the scenes.

- o **"Brute force" methodology,** is characterised by its seeking to generate an environment as faithfully as possible without resorting to any self-similitude parameter in its construction. This is the methodology more frecuently used in the generation of driving simulation games, such as *Trainz 2009*. This methodology uses continuous as well as discrete levels of detail. In both cases the need to represent the paths with a high degree of detail requires handling data structure and more complex calculations.

  If continuous lods are used, the latest trends point to lightening CPU load and speeding up CPU-GPU transfer using the new work primitive: the batch or tile (Livny et al 2007; Pajarola and Gobbetti 2007). In (Blow 2000), a detailed explanation can be found of the evolution of the algorithms for representing terrain in video games and the reasons behind the use of the batch. The batches or tiles are constructed in the pre-load time optimising to the maximum the organisation of the triangles they contain (strips). Thanks to the batch the selection metrics are no longer evaluated at a vertex level, but are performed at a batch level, enormously reducing the load of the CPU. Although this means the number of polygons to be displayed is less optimised, the high processing capacity of current GPUs means this is not a problem. However, the incorporation of paths leads to a big increase in the number of calculations so that the most up-to-date hardware is necessary (Bruneton and Neyret, 2008).This is the methodology used by the engines *Unreal* or *Crytek*.

  If a system of discrete levels of detail is used a series of handicaps have to be confronted:

  - the high memory consumption required to store the geometry associated with the different levels of detail during the pre-load time,
  - little constructive flexibility,
  - failure to make full use of the functionalities offered by present-day GPUS.

Weighing up the advantages and disadvantages of both methodologies together with the requirements demanded, as already seen in the introduction, modular technology opts for a tile-based methodology that integrates certain particularities that make it different from all other tiling systems utilised up to now. These particularities, which will be commented throughout the paper, have enabled the problems set out to be successfully solved.

Modular technology uses path tracking as the starting point of its designs and then, taking these, it generates the surrounding environment using the assembly and repetition of a finite number of modules. In this way, one of the basic tools for resource optimisation is exploited: instantiation. This is an innovation regarding the tile-based methodologies used up to now, which were lacking a positioning guideline. The use of these guidelines as starting point makes possible a precise and easy control of the level of detail of the surroundings of these guidelines. Modular technology takes advantage of the priori knowledge of these paths to generate

discrete pseudo-variant levels of detail with the view point. This is achieved by discretizing the environment transversally to the path.
Another innovation is that the modules used have different geometric shapes: a module is a straight fragment of environment curved a set of degrees. Calculating the number and optimum geometric design of the modules as well as the variety of their families will be decisive in obtaining the realism and refresh speed required in these displays.
The module positioning algorithm as well as the way of defining the tilesets, which in modular technology are called families, endow this technology with a greater constructive flexibility than other tile-based methodologies.
The outcome is a scene with all the required realism, with the desired refresh speeds, and with a comfortable communication interface with the simulation module and the graphic engine. All this is done completely automatically and with the possibility of easily inserting any environmental restructuring, something that is essential in this kind of virtual display. Moreover, the main problems associated up to now with the discrete level of detail adaptation algorithms (discrete lods) are eliminated:

- Thanks to instantiation and the shaders a straight module of each family need only be stored during the pre-load time, which means that memory ceases to be a problem.
- The scene is synthesised from a set of repetitive parameters, which means calculating is simplified.
- The modules are subjected to geometric transformations using shaders during execution time, which lets the realism of these scenes be enhanced. These transformations will be defined during the pre-load time by means of a set of parameters integrated together with the scene graph.

The modularity of the environment endows it with high constructive flexibility, with a large range of virtual scenes being able to be generated with a minimum of constructive parameters.

PREGENERATED MODULE-BASED MODULAR TECHNOLOGY

The module originates from a basic design made up of a straight longitudinal portion of the environment. This basic design is curved into a set of degrees forming what is called a basic set of modular components or modules (Figure 1). In this way the basic set is characterised by the existence of finite number of modules of fixed curvature and discrete curvature values.

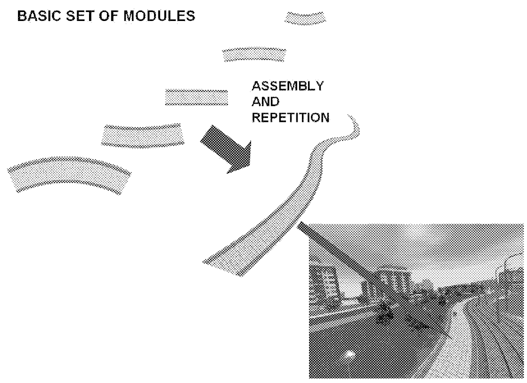

Figure 3. Basic set of modules

The module comprises three basic components: a longitudinal path and a set of transversal profiles with their corresponding textures (Figure 2).

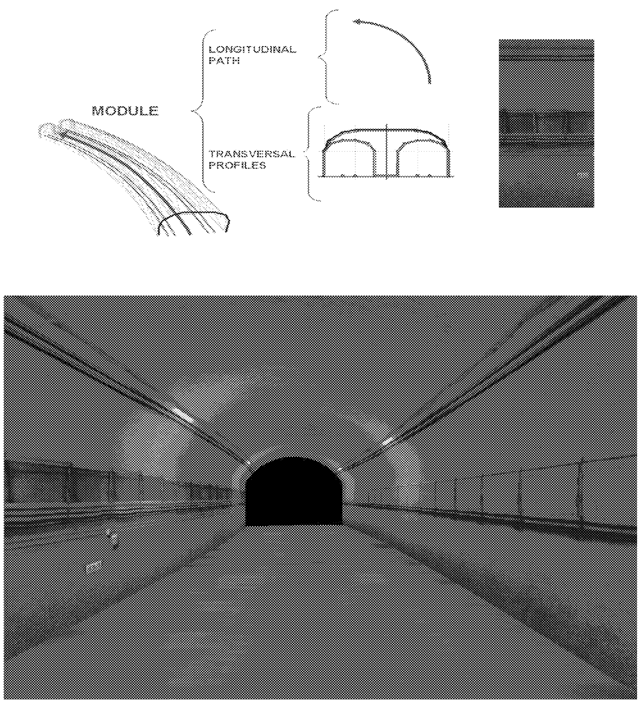

Figure 4. Components of a tunnel module.

The base set of modules together with a suitable positioning algorithm allows reproducing any geometry without holes or overlaps.
The next problem arises when attempting to calculate the transversal profiles of these modules so that they can reproduce any environment. So, the concept of a family of modules now appears as the base set of modules and shares the same definition of transversal profiles. These families will verify relationships of compatibility, which will be what ensures there are no incoherencies or discontinuities after the modules have been correctly positioned.

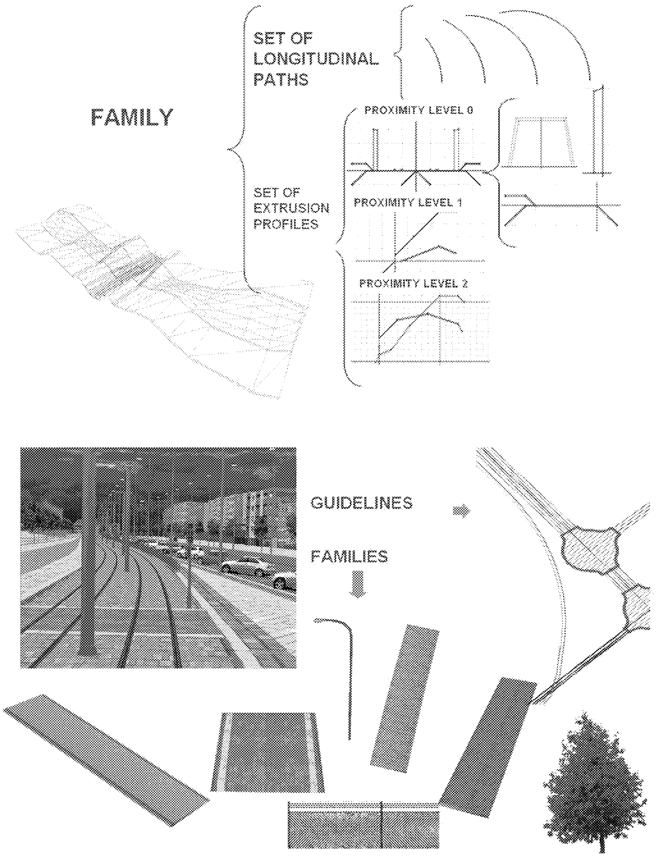

Figure 5. Families of modules (a) Components of a family. (b) Examples of families

GEOMETRIC SHADERS-BASED MODULAR TECHNOLOGY

The use of shaders lets each modular family be formed during the pre-load time by a single straight module. In execution time the shader will take charge of deforming this module until it attains the desired geometry. Thus, modelling effort is reduced as well as initial load times and the modular positioning algorithm (Tovar et al 2003) is made more versatile since the shader is capable of deforming the start and end sections of each module so that they fit perfectly without any spatial or tangential discontinuities. As a result, each family goes on to be formed in execution time by infinite modular components.

Total compound and corrected transformation shaders

The module is subjected to curving about the three cartesian axes which causes the displacement of the points belonging to their middle line. Figure 4 shows the displacement according to the axis, and of a point belonging to the middle line defined by its coordinate X_0.

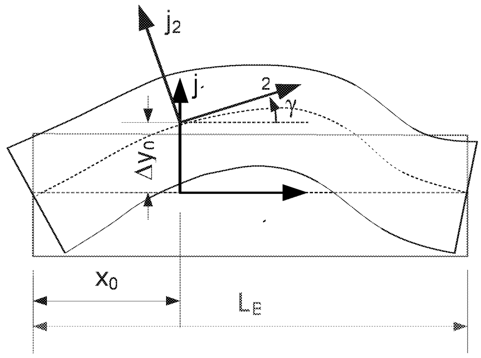

Figure 6. Displacement according to the axis and on deforming the module

The relation between the basic length of module L_B and the actual length it will occupy, Li, is corrected by applying an E_x scale:

$$E_x = \frac{L_i}{L_B}$$

$$L_i = E_x \cdot L_B$$

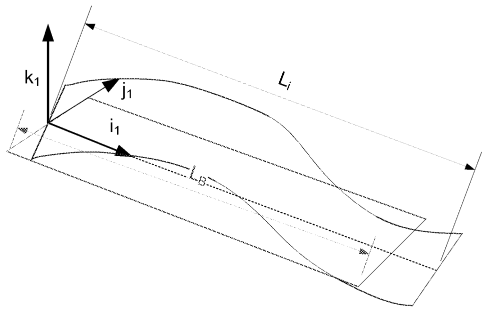

Figure 7. Straight module deformed by the shader

To define the displacement functions a third degree polynomial is used, whose imposed shape conditions are zero displacement and the conservation of the tangents at the ends. For example, for the case of displacement at y the displacement function would be:

$$f_{\Delta y}(s) \equiv \begin{cases} f_{\Delta y}(0) = 0 \\ f_{\Delta y}(1) = 0 \\ \dfrac{df_{\Delta y}}{dx_R}(s=0) = \tan\gamma_{ini} \\ \dfrac{df_{\Delta y}}{dx_R}(s=1) = \tan\gamma_{fin} \end{cases}$$

Where *s* is an adimensional parameter defined as:

$$s = \frac{x_0}{L_B}$$

$$0 \le s \le 1$$

Finally, the shader applies the rotations α(s), β(s) and γ(s) coherent with the displacements that have just been defined and which are obtained by deriving them.

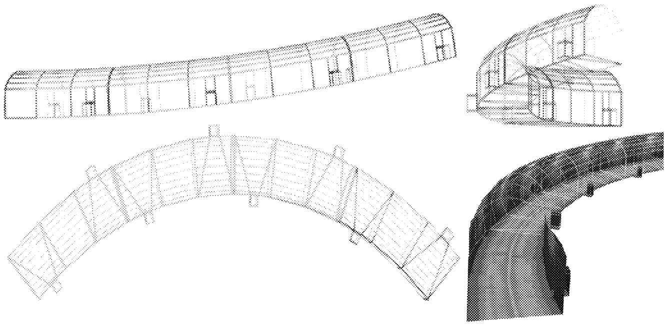

Figure 8. Sequence of various modules deformed by using shaders

APPLICATIONS

All virtual environment projects developed in CITEF have a modular component to a greater or lesser degree, which helps develop automation. Figure 9 shows different scenes that have been modularly generated where geometric shaders have been or can be applied. These scenes are taken from the virtual environments of the driving simulators (Nortes et al 2006) designed by CITEF for companies such as Metro de Madrid, CAF, Alstom and Invensys.

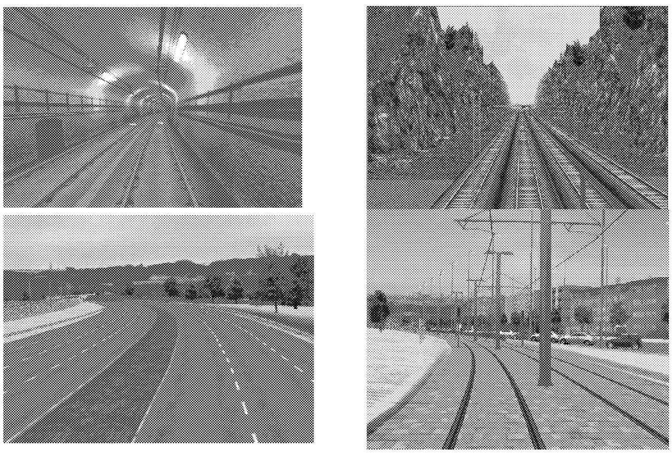

Figure 9. Examples of virtual environments created with the Modular Technology

CONCLUSIONS

From what we have seen from the applications used, we are convinced that modular technology has advantages when it comes to generating environments. Ten years of successful results in the generation of virtual environments for renowned driving simulators have proved it. Applying shaders increases the possibilities of modularity and with ever more powerful hardware the quality of virtual environments will increase spectacularly in the near future.

Future developments will be to apply geometric shaders that create the full modular geometry in execution time so that the scene is inserted parametrically in line with the profiles and paths with only the most singular and least modular geometry being loaded. Real-time generation would therefore be adaptive. The greater the capacity for geometric calculation, the greater the complexity and quality of the environment.

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CARLOTA TOVAR received her Mechanical Engineering Master degree from the Madrid Polithecnic University and her Master degree on Geographic Information Systems from the University Pontificia of Salamanca. She has been working for ten years in CITEF, Research Centre on Railway Technologies. Her main activities and research interests are mainly focused on the field of simulation, computer graphics, virtual reality and geographic information systems. Her main contribution is in the field of automatic generation of virtual environments. She has just finished her doctoral thesis on this subject. She has been actively involved in over 20 research and development projects.

AUTHOR LISTING

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