A Method for Simulating Players in a Collaborative Multiplayer Serious Game

Viktor Wendel, Johannes Alef, Stefan Göbel, Ralf Steinmetz
Multimedia Communications Lab
Technische Universität Darmstadt
Rundeturmstraße 10
Darmstadt, Germany
{viktor.wendel, johannes.alef, stefan.goebel, ralf.steinmetz}@kom.tu-darmstadt.de

ABSTRACT

Multiplayer Serious Games are a promising concept to combine the features of Serious Games with the concept of collaborative learning. Multiplayer games, however, are hard to model, especially as interaction between players is often hard to predict. For the design of multiplayer Serious Games, especially considering adaptation algorithms for multiplayer Serious Games, exhaustive tests are desirable. As real players are often hard to obtain, simulation of players might be a solution. In this paper we propose an approach to simulate human player behavior in collaborative multiplayer Serious Games. Our approach considers behavior in terms of gaming (player model), learning (learner model), and collaboration and teamwork (interaction model). The aim of our model is to have a sound foundation of realistic player behavior as a basis for evaluation of adaptation mechanisms in collaborative multiplayer Serious Games. We implemented our approach as an extension of the collaborative multiplayer Serious Game 'Escape From Wilson Island' and carried out a first evaluation. The results are promising as they indicate that it is possible to soundly and reproducibly simulate player behavior based on a player model, player skills as well as on teamwork and communication.

Keywords

Serious Games, Adaptation, Player Simulation

1. INTRODUCTION

Multiplayer Serious Games are a promising concept for collaborative learning. First concepts and prototypes already exist today, enabling new fields of research in this area. However, up until today evaluation data about collaborative games and collaborative learning in games is scarce. Particularly, in group learning it is desirable to be able to adapt multiplayer games to the needs, preferences, and varying skill levels of a multitude of players. Yet, for testing adaptation algorithms a lot of players are necessary. However, it is often hard to acquire reliable participants, especially if for a game session a fixed number of players is required. Especially players with desired characteristics (certain player model, state of knowledge) would be needed to perform sound evaluations. Therefore, it seems reasonable to simulate players and player behavior.

Many adaptation algorithms for games are based on player and learner models. Those models can also be used to model AI-based simulated players like the approach presented here. Simulating players, however, additionally needs to consider preferred play-style (player model), knowledge over the skills taught in the game (learner model), as well as information about player interaction including teamwork and communication (interaction model).

In this paper, we propose a concept for modeling and simulating players of a collaborative multiplayer Serious Game. Our concept defines the required interface to the game. This includes information needed from the game, like available player actions, skills to be taught, and relevant game information necessary to build the player model. Moreover, this includes possible player actions. The concept is based on player goals which again depend on their player model and skills. It uses plans to model complex player actions. It decides about which goal to be pursued next, based on the current state of the game and player interaction.

We implemented our concept on top of the existing collaborative multiplayer Serious Game 'Escape from Wilson Island' (EFWI). In a first evaluation, we could show that the simulated players behave differently dependent on their player model and initial knowledge (skills) in a replicable, reasonable and understandable way.

ACM International Workshop on Serious Games '14 Orlando, Florida USA
Copyright 2014 ACM 978-1-4503-3121-0/14/11 ...$15.00.
http://dx.doi.org/10.1145/2656719.2656723.

2. RELATED WORK

In this section an overview on related areas of research is provided showing how the work presented here relates to other work in those areas.

2.1 Collaborative Multiplayer Serious Games

The approach presented in this work focuses on collaborative multiplayer games. Those games are characterized by a game-play which is designed for a collaborative game experience, often with a focus on using or improving soft skills like communication or teamwork. As those aspects need to be considered in the simulation model, various approaches have been surveyed: Manninen and Korva [5] proposed a design concept for multiplayer puzzles based on different collaboration process types to be supported. Reuter et al. [6]

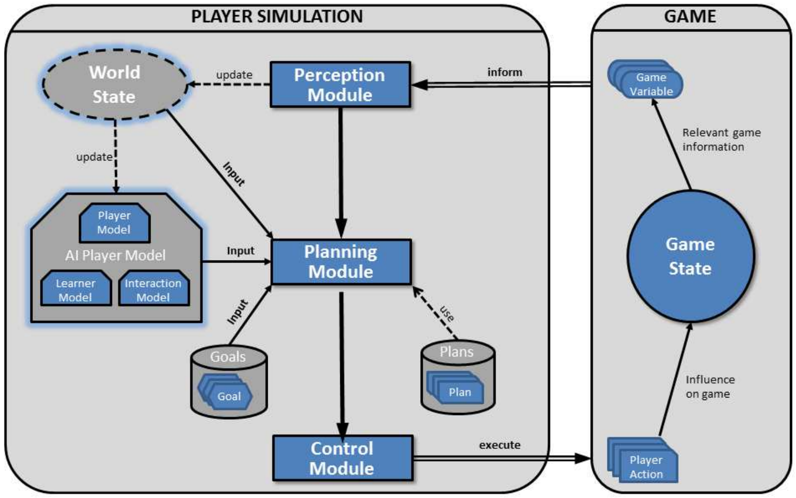

Figure 1: Simulated player.

presented a concept for game design patterns especially for collaborative player interactions. Zagal et al. [12] proposed a set of guidelines for designing collaborative games based on analysis of collaborative board games. Wendel et al. [11] proposed an approach for collaborative multiplayer design for a game for learning collaboration skills based on the guidelines of Zagal et al. [12].

2.2 Adaptation in Multiplayer Games

For adaptation concepts in multiplayer games, Kickmeier-Rust and Albert [3] provide a comprehensive overview. A core concept in this context is the term *GameFlow* [10] which refers to flow in games, i.e. to keeping players' skill-to-challenge ratio at an optimal rate. Therefore, player modeling is an important aspect as it is necessary to have a sound model of a player/learner in a collaborative multiplayer Serious Game in order to be able to adapt the game towards the needs, preferences, and skills of a player. Smith et al. [8] created a comprehensive taxonomy of existing player models. In the context of this work, the player models which fit best are those of Houlette [2] and Bartle [1]. Houlette's model uses player traits which can be defined according to the game. This is especially beneficial as it provides a very flexible player model which can easily be adapted to different games. Bartle's player model is commonly used in the context of role-play games and defines the archetypes 'explorer', 'socializer', 'killer', and 'achiever', which fits very well to the genre used here.

Regarding learner modeling, the competency-based knowledge space theory (CbKST) [4] seems promising for our concept. The model has been used bei Steiner et al. [9] for a learner model composed of a skill-based plan, a competence goal, the competence state, and the knowledge state.

2.3 Player Simulation Concepts

There are two main aspects of the simulation of a player. First, the structure that defines how the AI carries out its behavior. Second, there is the way the behavior is generated. An intuitive concept for the structure of an AI is the agent. Russel and Norvig [7] describe an agent as an entity that can perceive and influence its environment. The behavior of the agent is defined by its agent function. Russel and Norvig distinguish several types of agents:

The *simple reflex agent* only reacts to the current input of its sensors. Former percepts or actions are not considered for choosing an action. The *model-based reflex agent* enhances this agent by also considering the state of a world model which is updated with its percepts and actions. As these two agent types only apply rules to the situation, they can only achieve one implemented task. To enable an agent of achieving different tasks it must have a way to choose between different tasks. The *goal-based agent* extends the *model-based reflex agent* by introducing goals, which are defined as world states the agent wants to be in. The agent chooses its actions depending on the goal it wants to achieve. A more complex variant of the *goal-based agent* is the *utility-based agent*. This agent does not try to reach a certain world state but rather evaluates the reachable world states and tries to reach the one that is best for it. This agent is fit best when there are conflicting or constantly changing goals.

To reach complex goals an AI must form a plan, i.e. a sequence of actions. The most simple way of letting the AI form a plan is to provide it with a plan library which holds at least one plan for each goal. The AI only has to choose the best available plan. This method is fast in computation but lacks the flexibility of creating a plan on the fly. Russel and Norvig [7] describe several methods of planning. Among them are search in state space, Planning Graphs, Situation Calculus and generating partially ordered plans. Generating a plan is very computation intensive and becomes very slow with growing numbers of possible actions. This can partially be countered by using efficient heuristics.

3. CONCEPT

Collaborative multiplayer (Serious) games can be characterized as highly dynamic. Thus, player goals might constantly change. Therefore, players are modeled as a *utility-based agent* as this kind of agent can deal best with those circumstances. Players are modeled with the components shown in Figure 1. The simulated player receives information about the game world from the game itself. The information is processed in the*Perception Module*. Using this information, the simulated player holds a state of the world (*World State*). The *Simulated Player Model* contains data about the current player model, learner model, and interaction model. It is updated when relevant game states change, like when the player receives vital knowledge, etc. A *Planning Module* periodically evaluates the *Simulated Player Model* and current information about the game world in order to decide which plan should be executed next. Therefore, a plan library is used which holds a set of predefined plans. The *Control Module* decides which game actions the simulated player should execute based on the current plan and *Simulated Player Model*. The input from the *Simulated Player Model* is mainly used for communication related actions.

3.1 Basic Definitions

Definition 1. A *Game Variable* $v \in V$ is an elemental piece of information about the game. Game variables can change either through game mechanics and events or through *Player Actions*.

Definition 2. A *Player Action* $a \in A$ is an isolated action in the game which can be performed by the player. The action has a well-defined effect on the game and/or the player. Examples are 'walk to', 'gather berry', 'fell palm'. All available *Player Actions* are defined via the game interface including relevant parameters and effects.

Definition 3. A *Skill* $s \in S$ is a game relevant piece of knowledge (e.g. 'I can eat berries to increase my saturation') or motor skill (e.g. carrying palm). $f : S \rightarrow [0; 1]$ assigns a value to a skill s, such that $s = 0$ means that the skill is not learned and $s > \gamma$ means the skill is learned, whereas γ is a predefined threshold (e.g. 0.75).

Skills can be learned (i.e. the skill value increases) by doing related actions or by gathering relevant information. Teamwork and communication between players is modeled using two special skills 'Teamwork' and 'Communication'. 'Teamwork' is multiplied by the respective skill related to a collaborative task. The 'Communication' value decides about with what probability a player passes on knowledge to other players.

Definition 4. A *Player Goal* $g \in G$, with $g = (pi, K \subseteq S, gc \in GC, P' \subseteq P)$ is an elementary objective which the player pursues. *Player Goals* define what a player needs to do in order to successfully play the game. They consist of a *Player Interest* pi, a set of *Knowledge Preconditions* $K \subseteq S$, a *Goal Condition* $gc \in GC$, and a set of *Plans* $P' \subseteq P$ fulfilling the goal.

Definition 5. The *Player Interest* $pi \in PI$, $pi^T = (pi_1, pi_2, ..., pi_n)$, $pi_x \in [0; 1]$ defines how a goal matches to a player's player model shaping, e.g. (using Bartle's player model [1]) if the goal is rather pursued by an achiever or by an explorer. The *Player Interest* is an n-dimensional vector which assigns a value of $[0; 1]$ to each player model trait pi_x. Example: $pi = (0.0, 1.0, 0.5, 0.5)$ (using Bartle's player model with the traits: explorer, achiever, killer, socializer) would mean that the *Player Goal* would be pursued strongly by players who have high achiever shaping, and moderately by players with a high killer and socializer shaping in their player model.

A *Player Interest* can be defined statically (like in the previous example) or dynamically. A dynamic *Player Interest* is changed by a multiplier depending on game variables. For example, the 'Increase Saturation'-goal has a $pi = (0.25, 0.25, 0.25, 0.25)$ *Player Interest*. The *Player Interest* is changed with respect to the current saturation such that a lower saturation results in a higher rated goal for all player model traits.

Definition 6. A *Goal Condition* $gc \in GC$ is a game condition which needs to be fulfilled for the goal to be accomplishable. The information is gathered from the game itself (using game variables) and stored in the world state. The *Goal Condition* is formulated as a boolean expression using a set of game variables $V' \subseteq V$.

Definition 7. A *Knowledge Precondition* $K \subseteq S$ is a set of player conditions which needs to be fulfilled for the goal to be accomplishable. The condition is fulfilled if the player 'knows' the required skill.

Definition 8. A *Plan* $p \in P, p = (A' \subseteq A, K \subseteq S, GC' \subseteq GC, w)$ is a set of *Player Actions* $A' \subseteq A$ which are to be executed in a defined order, a set of *Knowledge Preconditions* $K \subseteq S$, and a set of *Goal Conditions* $GC' \subseteq GC$ which need to be fulfilled for the plan to be executable. In addition to that, all plans for a goal are ordered using a weighting w to prioritize the execution of plans when more than one plan for a goal is executable.

3.2 Simulated Player Model

The simulated player model consists of three elements: The *Player Model*, the *Learner Model*, and the *Interaction Model*, representing the simulated player in terms of gameplay preferences, knowledge, and collaboration/teamwork skills.

3.2.1 Player Model

The player model represents the simulated player's preferences in terms of play style. Depending on the underlying Serious Game, a set of traits is defined which represent possible player preferences. Those traits can represent global player preferences like 'action-oriented' or 'defensive'. Or those traits refer to more fine-grained traits like 'prefers to use ability x'.

The traits defined in the player model are identically equal to the traits of a player interest of a goal. Thus, it is possible to define a metric to calculate how attractive a goal is for a player depending on his/her player model.

3.2.2 Learner Model

The learner model defines which game-relevant skills a player has. Skills are modeled following the Competence-based Knowledge Space Theory [4] which uses Hasse diagrams to order skills hierarchically and to model prerequisites between skills as relations. Thus, the learner model is described by the partially ordered set of skills and dependencies between those skills.

3.2.3 Interaction Model

The interaction model represents how well players can communicate with each other and to which extend they are able to perform in a team. A good communication means that players recognize relevant pieces of information and moreover, recognize that they should forward that information to one or more team members. Thus, information is modeled as a skill (in the learner model). Having the skill learned means knowing the information. Communication is modeled as a special skill defining to which extend (i.e. probability) the player forwards information once he/she receives them (i.e. learns the respective skill). Teamwork is also modeled as a special skill which is used as a multiplier for skills which require collaboration.

3.3 Simulation Execution

For each simulated player, the simulation determines the next goal when the current goal is accomplished or when it cannot be accomplished any more. The next goal is determined comparing the player model with the player interest for each goal with regard to goal conditions and knowledge preconditions. The most fitting goal is chosen according to a metric to define the appropriateness of a goal. Therefore, first all goals are filtered, checking if their *Goal Conditions* and *Knowledge Precondition* are accomplishable. Each accomplishable goal's *Player Interest* vector gets then compared to the player's player model vector using the scalar product. Thus, the goal with the *Player Interest* which is most similar to the current player model shaping will be chosen. The goal with the highest value is chosen and gets processed by executing one of its available plans. Available plans are filtered depending on their preconditions. The valid plan (i.e. all preconditions fulfilled) with the highest weighting w gets executed. Executing a plan means that the plan's actions are executed in the defined order.

4. IMPLEMENTATION

4.1 Escape From Wilson Island

We implemented our concepts as an extension of the existing collaborative multiplayer Serious Game *Escape From Wilson Island*. The game was developed for training and assessment of collaborative and teamwork skills. It is best described as a 3rd person action-adventure like game for four players. The narrative background is a Robinson Crusoe-like scenario with the players being stranded on a deserted island. Their goal is to flee from there. In order to achieve that they need to build a shelter, find food, build a raft and ignite a signal fire on a neighboring island. All underlying tasks are designed in a way such that players need to collaborate. One collaborative task is carrying a palm over the island. Players need to coordinate their movements so that they do not let the palm fall. This requires an extensive amount of coordination and communication. Other teamwork-oriented features include the collection and distribution of food among team members. Figure 2 shows three players carrying a palm while the fourth player is gathering berries. For more detailed information about game design decision see [11].

4.2 Player Simulation

4.2.1 EFWI Skills

There are several skills to be mastered in EFWI. Some of these skills do not have preconditions. For example there is no knowledge a player must have before he/she can learn that he/she can gather berries from a bush. Some skills however have other skills as preconditions. For filling an empty bottle with gas the players must first have knowledge where to find a geyser and that there is a bottle to find in the first place. Other motor skills are carrying a palm and hunting herons, both requiring the players to first have some basic knowledge that these actions can be executed.

4.2.2 EFWI Actions

The players can perform several different actions, e.g. fell a palm, gather berries or carry a palm. Some of the available actions, like felling a palm, do not require a skill since the player only has to decide to execute this action for it to be executed. Actions like carrying a palm however require the players who are carrying the palm to stay inside a certain area around the palm while carrying. If one player steps out of his/her area, the palm is dropped. These actions have associated skills that influence the player's performance while executing the action. For carrying a palm this lack in performance is simulated with a randomized offset on the walking direction. The lower the skill level of the player the higher the possible random offset which lets the player more likely step out of his/her carrying area and therefore drop the palm. Furthermore the 'Teamwork' skill also influences this performance, giving good team players a bonus and a penalty to bad team players.

4.2.3 EFWI Goals

In EFWI the players have several goals that they can or must achieve during the game. One of the first things players will do at the start of the game is gathering information of where they are and what is going on. They can achieve this by exploring the island on their own or by talking to the NPC standing at the beach where the game starts. Exploring the island has only the precondition that the island has not yet been completely explored. Therefore it is available at the beginning of the game. Talking to the NPC at the beach has the preconditions that the player has not yet talked to him and that the NPC in fact is still at the beach. Exploring the island is more interesting for players that have a high explorer trait. Talking to the NPC will more likely be interesting for players with a high socializer trait.

Another main goal is building the hut. Players with a strong achiever trait will try to achieve this as it is one of the most visible successes in the first part of the game. Building the hut has only two conditions for the world state: The hut has not yet been built and there must be palms. Building the hut also requires several skills: The player who wants to build the hut must 'know that the hut can be built' and 'where it can be built'. To carry a palm it first has to be felled. As only one player has the axe that is needed to fell the palm there are two available plans for building the hut. The first plan requires the player to have the axe in his/her inventory. In this case the player can simply fell the palm himself/herself. The second plan does not require an axe but the player has to ask the player with the axe for help.

Some goals have dynamical *Player Interests*. Goals that improve status values of the player, like saturation, become more important once the value decreases. In addition to that, a cool-down function prevents players from trying to achieve some goals over and over again.

4.2.4 EFWI Player Model

In EFWI, the player model traits are defined similar to the player model of Bartle using four traits for four different

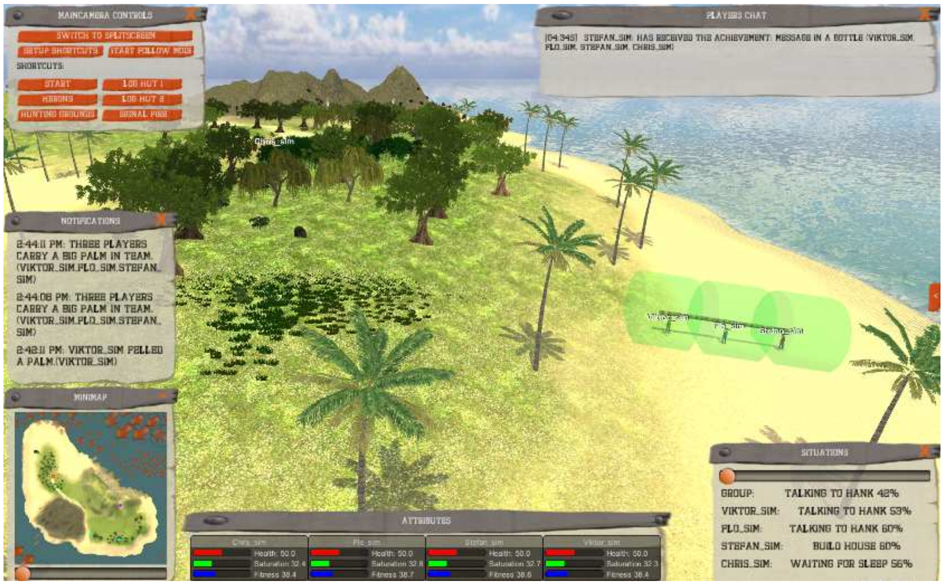

Figure 2: Three players carrying a palm, one player gathering berries.

player types: explorer, achiever, socializer, and killer. To rank actions or goals a function is provided that maps the *Player Interests* to a numerical value. This function is realized as the scalar product of the traits of the player and the traits of the *Player Interest*.

4.2.5 EFWI Learner Model

The learner model in EFWI is based on CbKST [4], i.e. it uses a skill tree with interdependencies (i.e. prerequisite relations) between skills. Skills can be learned in several ways. Motor skills are increased by small amounts when the player is executing the related task. These skills can also be increased when other players or the NPC share knowledge about this skill, e.g. the NPC tells the player how to hunt a heron. Skills that represent knowledge can be gathered from other players or the NPC and for some skills also by walking around the island. For example, whenever a player is close to a berry bush, 'gather berries' knowledge is increased to simulate that a real player would notice the highlighted bush and try to interact with it.

The skill 'Teamwork' is increased whenever a player executes a teamwork task. The skill 'Communication' is increased when a player shares knowledge with others or when he receives knowledge from other players. As some skills do not have predecessors they represent leaves in the skill tree. These skills can be learned as soon as a learning condition is met, e.g. gathering berries can be learned whenever a player is close to a berry bush. The knowledge that the player can interact with trees is a prerequisite to learning how to carry a palm. As soon as the player has learned this skill he/she can learn how to carry a palm. This in turn enables the player to gather knowledge about building the hut and the raft. If the player knows about building the hut he/she can learn from the NPC about sleeping in the hut and that it helps recovering energy.

4.2.6 EFWI Interaction Model

There are two main interaction forms in EFWI. The first one is communication. The players have to communicate with each other to get help for group goals and to share information. The second form is actual teamwork where the players have to coordinate their behavior.

The implemented interaction model provides the players with the capabilities to share knowledge and ask for help. Teamwork is modeled as a special skill which is multiplied with the required skill whenever a collaborative task is solved by the team.

Table 1: Evaluation Parameters

Ind. Variable	Variable Values			
Player model	Achiever	Expl.	Social.	Killer
Learner model	All skills = 0		All skills = 1	

4.3 Evaluation

An evaluation has been carried out to assess the realistic functionality of the player simulation.

4.3.1 Setup

For a game session, all four players were simulated. Three series of measurements were carried out. Independent Variables (IV) are the player model shaping, the learner model shaping, and the interaction model shaping. In the first series of measurements, the player model was varied while the learner model were set to the lower value (all skills = 0) and the interaction model was set to a neutral value of (teamwork = 0.5, communication = 0.5). All four players were set to the same player model, i.e. four achievers, four explorers, four socializers, or four killers. The player model for an achiever for example was set to $(1.0, 0.0, 0.0, 0.0)$. For the other shapes it was set respectively.

In the second series of measurement, the player model was fixed to a neutral player model (0.25, 0.25, 0.25, 0.25) for all players. The interaction model was set to a neutral value of (0.5, 0.5). The learner model was varied from a shaping of (all skills = 0) to a shaping of (all skills = 1).

Table 2: Goal Achievement Times

Goal	all skills = 0	all skills = 1
TalkToHank	$0.00 \pm 0.00[s]s$	$0.00 \pm 0.00[s]$
Explore	$34.23 \pm 25.91[s]$	$32.98 \pm 27.22[s]$
ImproveSaturation	$37.82 \pm 19.24[s]$	$43.50 \pm 26.02[s]$
BuildHut	$36.74 \pm 8.19[s]$	$17.65 \pm 2.24[s]$

In the third series of measurement, the player mode was again fixed to (0.25, 0.25, 0.25, 0.25) for all players. The learner model was set to (all skills = 0). The interaction model was varied from a very bad interaction (0.0, 0.0) to a very good interaction (1.0, 1.0).

Table 1 summarizes all three independent variables and the values chosen. Each setting was repeated four times.

4.3.2 Results

In the first series of measurements (IV: player model), a significant difference in player behavior could be observed. In the setting with four achievers, the players were the fastest to talk to the NPC and build the log hut, they were however late to start exploring the island. This can be regarded as a realistic behavior, as we do expect achievers to try to fulfill the game relevant tasks as fast as possible. In the setting with four explorers, the players immediately started exploring the island. Subsequently, building the log hut was of a lower priority. The socializers at first interacted with the NPC whenever possible. Thus, they immediately gathered the required knowledge to build the log hut which they did next. After that they explored the island and gathered food. The killers played the game rather selfishly. They started exploring the island and gathering food. Thus, they needed much longer to talk to the NPC and to finally build the hut.

In the second series of measurement (IV: learner model), we could observe that the simulated players were much faster at completing the relevant goals with (skills = 1) compared to the setting with (skills = 0) (see Table 2). This is due to the fact that the simulated players do know what to do and that they are more effective at doing it, e.g. the 'skilled' players needed only one attempt to carry each palm whereas the 'unskilled' dropped some palms until their motor skill 'CarryPalm' was high enough. Table 2 shows how long the simulated players on average needed to fulfill a task.

In the third series (IV: interaction model) we could observe that players were as expected faster in the collaborative task (buildHut) with the high collaboration settings compared to the lower settings. The simulated players were faster at carrying the palms (because the higher teamwork skill positively influences skills which require collaboration, like 'carryPalm'). Also, all new information was immediately passed to other players.

Altogether, it can be stated that the simulated players behave as expected in terms of player model, learner model, and interaction model. It appears to be possible to simulate player behavior by adjusting the player model, learner model, and interaction model.

5. CONCLUSION

In this paper we proposed an approach to simulate human player behavior in collaborative multiplayer Serious Games. Our approach considers behavior in terms of gaming (player model), learning (learner model), and collaboration and teamwork (interaction model). The aim of our model is to have a sound foundation of realistic player behavior as a basis for evaluation of adaptation mechanisms in collaborative multiplayer Serious Games without the need of a large number of real participants. We implemented our approach as an extension of the collaborative multiplayer Serious Game *Escape From Wilson Island* and performed a first evaluation. The results are promising as they indicate that it is possible to soundly and reproducible simulate player behavior based on a player model, player skills and teamwork as well as communication.

However, further evaluation is required to confirm the correctness, usability and transferability of our model. More realistic player settings need to be evaluated using real player model data and skill settings. Moreover, the concept should be evaluated using a different game with different skills, actions, and player traits. Another shortcoming of the approach presented here is that it only simulates interaction on a gameplay level, not on a verbal level.

6. REFERENCES

[1] R. Bartle. Hearts, clubs, diamonds, spades: Players who suit MUDs. *Journal of Virtual Environments*, 1(1):19, 1996.

[2] R. Houlette. Player modeling for adaptive games. *AI Game Programming Wisdom II*, pages 557–566, 2004.

[3] M. D. Kickmeier-Rust and D. Albert. Educationally adaptive: Balancing serious games. *Int. Journal of Computer Science in Sport*, 11(1), 2012.

[4] K. Korossy. Modeling knowledge as competence and performance. *Knowledge spaces: Theories, empirical research, and applications*, pages 103–132, 1999.

[5] T. Manninen and T. Korva. Designing Puzzles for Collaborative Gaming Experience–CASE: eScape. In S. Castell and J. Jennifer, editors, *DiGRA 2005 Conference: Changing Views - Words in play*, pages 233–247, Vancouver, Canada, 2005.

[6] C. Reuter, V. Wendel, S. Göbel, and R. Steinmetz. Game design patterns for collaborative player interactions (accepted for publication). In *Proceedings of the Digra 2014*, Aug 2014.

[7] S. Russell and P. Norvig. *Artificial Intelligence: A Modern Approach*. Prentice Hall, 2009.

[8] A. M. Smith, C. Lewis, K. Hullet, and A. Sullivan. An inclusive view of player modeling. In *Proceedings of the 6th International Conference on Foundations of Digital Games*, pages 301–303. ACM, 2011.

[9] C. M. Steiner, A. Nussbaumer, and D. Albert. Supporting self-regulated personalised learning through competence-based knowledge space theory. *Policy Futures in Education*, 7(6):645–661, 2009.

[10] P. Sweetser and P. Wyeth. Gameflow : A model for evaluating player enjoyment in games. *Computers in Entertainment (CIE)*, 3(3):1–24, 2005.

[11] V. Wendel, M. Gutjahr, S. Göbel, and R. Steinmetz. Designing Collaborative Multiplayer Serious Games. *Education and Information Technologies*, 18(2):287–308, 2013.

[12] J. P. Zagal, J. Rick, and I. Hsi. Collaborative Games: Lessons Learned From Board Games. *Simulation and Gaming*, 37(1):24–40, 2006.