

Artificial Subjects in Psychological Experiments based on the "Socially Augmented Microworld (SAM)"

H.D. Burkhard¹, L. Jahn¹, S. Kain², C. Meyer², J. Muetterlein², J. Nachtwei², N. Niestroj²,
S. Rougk², M.C. Schneider¹

Humboldt-Universität zu Berlin, Germany
1 Institute of Informatics, 2 Institute of Psychology

(hdb@informatik.hu-berlin.de, jahn@informatik.hu-berlin.de, saskia.kain@zmms.tu-berlin.de
charlotte.meyer@hu-berlin.de, muetterj@cms.hu-berlin.de, jens.nachtwei@hu-berlin.de,
nicolas.niestroj@hu-berlin.de, sabine.rougk@cms.hu-berlin.de, schneid@informatik.hu-berlin.de)

Abstract. The paper reports on an ongoing interdisciplinary project in the field of Human Factors concerning Psychologists and Informatics. Artificial agents are constructed as navigators to replace human subjects of a socially augmented microworld. The task of the agents concerns the cooperative control of an object along a given track. The approach will serve to compare human and artificial performance in psychological experiments. A theoretical and methodological approach is presented. Implications for the future are discussed.

Keywords. Microworld, social interaction, human performance, automation, simulation, artificial agents, cooperation

1 Introduction

Human Factors Scientists and practitioners are interested in measuring performance of operators supervising and controlling complex technical systems (field of Human-Computer-Interaction; HCI (e.g. Dix, Finlay, Abowd & Beale, 1992; Wandke, 2005) as in cockpits or control rooms of power plants. Multi-determination of human behavior is particularly pronounced in these complex settings: Operator's performance is – to a much greater extent – influenced by multi-faceted factors (Gérard, Huber, Nachtwei, Schubert & Satriadarma, 2011) because of complex and highly demanding settings. In addition, performance of *operators* interacting with a complex technical system in real time depends at least in part on the *developers* – the intelligence behind these systems (Wandke & Nachtwei, 2008; Norman, 2007). How developers support cooperation of technical system and human operator in foreseeable standard situations as well as novel, unexpected situations is key to the quality of human-computer-interaction and hence to a successful future of these systems (Dekker & Woods, 2002). Thus tracing operators' performance to one specific factor is a lot more difficult than it is for subjects of stimulus-response experiments (Huber, Kain & Nachtwei, 2008). Microworlds have become increasingly popular particularly with regard to Human Factors research (Parasuraman, Sheridan & Wickens, 2008; Sapateiro, Ferreira & Antunes, 2011). They offer one approach to control and explain the comparably greater amount of variance in Human Factors studies. Two distinct fields of their application have emerged:

Simulating human decision making in complex situations (e.g. Funke, 1998) vs. simulations as models of realistic work contexts/(complex) technical systems, with the latter being characteristic for Human Factors Research. A number of simulations in the field of supervisory control (e.g. Sheridan, 2002) emerged as a result of advances in computing technology notably in the 1980s. What all these Software applications have in common is their approach of modeling reality's complexity and dynamics to examine (multi-determined) behavior under controlled laboratory conditions (DiFonzo, Hantula & Bordia, 1998). A prominent example is the so called *Cabin Air Management System* (CAMS; Sauer, Wastell & Hockey, 2000). However, traditional microworlds either suffer from deterministic functions and thus from in principle foreseeable events - even if they are highly complex and interdependent, or they contain stochastic parts making prediction impossible (Gross & Nachtwei, 2007). Hence a level of high but at least afterwards explainable complexity is missing in these kinds of simulations.

2 Empirical base for the development of artificial agents

The Socially Augmented Microworld as the empirical base

In order to escape determinism and at the same time not to exceed complexity Wandke and colleagues at the Psychological Institute of Humboldt-University Berlin used a whole new approach for developing a new type of simulation: The "Socially Augmented Microworld" (SAM). As an originally existing microworld (a tracking experiment) lacked complexity for human operators (subjects, who were instructed to supervise and control the tracking) the aim was to make the experiment more challenging for these subjects. Based on indications that social interaction may serve to enhance complexity (Nachtwei & Meyer, submitted) two real persons were added to an existent microworld as so called "Microworld Inhabitants" (MWI) to perform a cooperative pursuit tracking task (see figure 1): Both MWIs are given joysticks to navigate the same object along a track displayed on a monitor ahead of them.

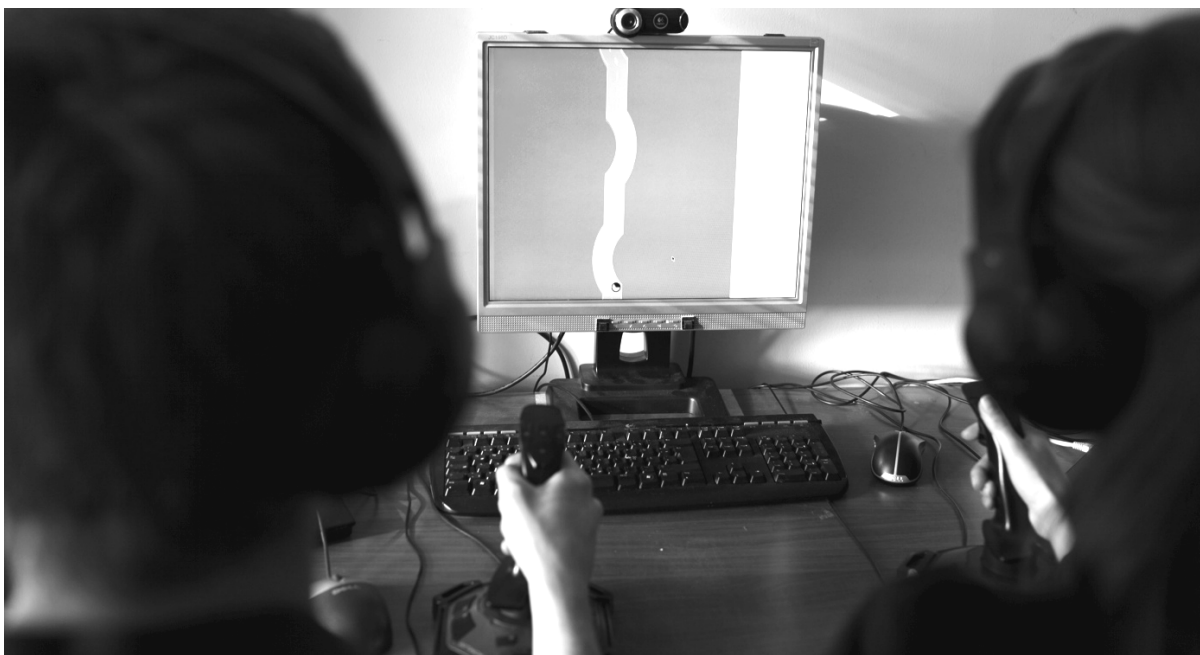


Fig. 1: The Socially Augmented Microworld (SAM): Two subjects as microworld inhabitants (MWIs) performing the cooperative pursuit tracking task.

Each MWI is assigned with 50% vertical and horizontal joystick input forcing both MWI to cooperate while doing the tracking safely (avoiding collisions with obstacles, making a choice of direction at forks of the track) and quickly.

The lab system surrounding the Socially Augmented Microworld

SAM is one essential part of a far more complex lab system. Thus before we continue to expand on objectives and methods of the interdisciplinary project dealing with SAM (only) we complete the description of the entire lab system.

The two MWIs performing the cooperative tracking task are in turn supervised and supported by an automation designed by developers or a third person: a human operator who is instructed to optimize MWIs' tracking performance (speed and accuracy). In real human-computer-systems the role of an operator is often described as a supervisor and controller or supervisory controller (Usher & Kaber, 2000; Sheridan, 2002): Operators (like pilots, air traffic controllers or controllers in process control stations) have to monitor a complex, dynamic and at least partly automated process for long periods of time in "normal" states of a system. There is either no intervention or simply small adjustments to make sure the system remains in its normal state (e.g. give hints to pilot, change temperature in a vessel). "Abnormal" states require operator's interventions, contingency evaluation and replanning activities (Woods & Hollnagel, 2006). Thus they need to react promptly to changes in the system's parameter usually in a way they are told to or they are trained for.

The human operator in the underlying experimental set up is exposed to similar demands. He has to supervise MWIs' tracking performance using an interface. This supervisory control master display consists of a video of MWIs' faces and upper parts of the body, a track preview and other sources of information. To enhance MWIs' tracking performance (and effort) he may give visual and audio hints or warnings or may directly manipulate navigation of each or both MWI (e.g. by limiting the object's maximum speed). To identify a near-optimal version of this interface a series of studies was conducted using different extensions of the interface: A prefinal extension was compared to the final, actual version of the interface which contained a greater amount of information for the operator (i.e. a greater number of displays, inputs and outputs). Operators using the final interface were able to significantly reduce effort of the two MWIs (Nachtwei & Meyer, submitted). In correspondence results indicated that interface modifications lead to changes in operators' situation awareness: operators' showed a remarkably higher Situation Awareness regarding the recognition of MWI's effort. In addition, effects of operators' emotional stability on handling of the lab system could be replicated in different analyses. The results support the value of SAM plus interface for measuring operators' performance in human-computer-systems as valuable indications, e.g. criteria for designing interfaces of real technical systems, may be derived from these studies.

ATEO: Division of Labor between Developers and Operators

The entire system comprising SAM (cooperative tracking of the two MWI) and Interface (so called ATEO Master Display (Nachtwei, submitted) used by a human operator to optimize MWIs' performance and effort) was created over a period of three years as a first-of-a-kind

lab system, so called ATEO Lab System (ALS). Its experimental setup is illustrated in figure 2. ATEO refers to the German title of the umbrella project for developing the ALS: Division of Labour between Developers and Operators – a project emphasizing the need for paying (more) attention to developers of human-computer-systems (Cummings & Thornburg, 2011) rather than just superficially comparing strengths and weaknesses of humans with those of machines. The ALS now serves as the heart of this project as it offers a unique value: While the appeal of comparing developers' vs. operators' performance itself is widespread by now in Human Factors community there has never been used a common, *empirical* reference point for comparing both groups. SAM does indeed represent *one and the same* experimental basement to measure both developers' performance (conceptualizing automation for human behavior in social interaction and cooperation) as well as operators' performance (supervising and controlling a complex, dynamic technical process).

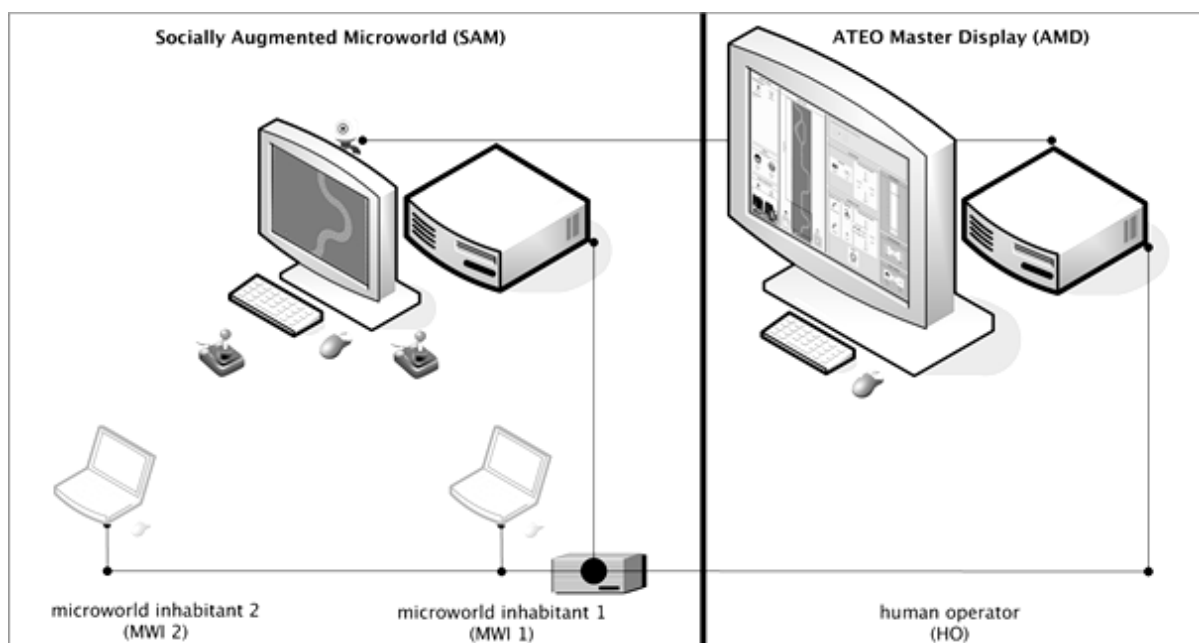


Fig 2: Experimental setup of the ATEO lab system (ALS) comprising two main interacting human(s)-machine subsystems SAM and the AMD. In SAM two real people (the MWIs) are included as part of a complex, dynamic system performing a pursuit tracking task and each self-reporting their effort (measured by items of the adapted Rating Scale Mental Effort (Zijlstra & van Doorn, 1985) presented on laptops). Tracking performance and effort of MWIs were made accessible to a non-visible (hence the black line) third person: the human operator who has to supervise their tracking (and may register MWIs' effort) behavior through the AMD.

The Developer behind the Automation

For more than six years the developer behind the automation has been studied in this project to shed light on the question of function allocation between human operators and automation from an empirical perspective. Cordula Krinner (2009) asked subjects in four studies to design concepts of automations to assist the two MWI with their tracking task while varying independent variables, e.g. type of information, team composition or expertise in matters of human computer interfaces.

The major study during the second phase of the project focused on the amount of information and involved subjects who worked as developers for different companies and research facilities. They all shared the aspect of being experts in the field of HCI as they held many

years of professional experience. 30 teams of three members each were asked to design automations supervising and controlling SAM to identify differences between the groups due to their differing amount of information. The data is still under examination and for the first time the concepts designed will be implemented by several students of computer sciences.

How can Artificial Intelligence support research in the field of human-automation-interaction?

The approach of including real persons into an experimental setting has its drawbacks. Studies using the ALS require 3 subjects per trial (each human operator is combined with two (new) MWIs). Consequently required sample sizes need to be tripled each time a study is conducted to measure operators' performance (and other variables like Situation Awareness, Mental Workload). This is a very costly approach entailing great administrative and organizational expense. A further, less practical consideration is the fact that automation is in the move to replace human operators. Thus progressions in the field of human-automation-interaction and especially within the project ATEO must be made to identify (1) if and how (well) automation may simulate actual human behavior and (2) derived from limits of this simulation: which functions and tasks should remain in the hands of humans to ensure safe and efficient performance. In an interdisciplinary project of Informatics and Psychologists we have been attempting to develop artificial agents acting similar to humans. Since human subjects need to be paid and are difficult to hire, artificial agents will serve to perform a greater number experiments by less organizational or financial effort. Moreover, they can be used for dedicated settings of the experiments, e.g. repeating experiments with identical behavior of the artificial inhabitants, while human subjects may act differently during repetitions. So they may provide a deeper insight in operators' behavior identifying strengths and weaknesses which are then comparable to those of automation. Central to this project is the earlier depicted Socially Augmented Microworld (SAM) which serves as an example of a complex dynamic system under the control of a human operator. Its two (real) MWIs are going to be replaced by artificial inhabitants. The approach will be described in the next section.

3 An interdisciplinary approach for the development of artificial agents

3.1 General procedure

Our aim is the development of artificial agents and their implementation into SAM (see section 1). Note an agent simulates a human's *interactive* performance: SAM originally comprises two single human microworld inhabitants (MWI) who cooperatively navigate an object along an existent track. Due to their interaction while cooperatively performing the tracking task these two MWI represent a complex dynamic – and unforeseeable – system which is later supervised and controlled by the human operator. Thus artificial agents do not map a single MWI's "pure" performance (navigating without the other MWI) but map MWI's single performance interacting and adjusting to the other MWI's performance (navigating in cooperation with the other MWI). Therefore the term *interactive performance* is used in the following to describe a single MWI's behavior, which is influenced by the behavior of the other MWI. The simulation of SAM's environment (track and object) is based on the software

framework of SAM. It provides a visual image of the scene, detects the joystick commands and updates the situation accordingly each 39 milliseconds.

Procedures of design and implementation of the agents are drawn from our experience with the development of soccer playing robots (Nao-Team Humboldt, 2011). Agents interact as autonomous programs with the elements of SAM's environment (object and track). They receive inputs regarding object's actual position on a section of the track by simple codings, and they can send signals like those from a joystick to the SAM system.

In this stage agents are developed in a simple version always reacting in the same way on identical information ("reactive behavior"). Agents may represent different types of MWIs' interactive navigation behavior. These types are operationalized by related parameters such as acceleration/deceleration and joystick deflection over various situations. To this end logfiles of behavioral data gained in former experiments are examined and classified in order to distinguish different human navigation styles. In a first approach described below, the classification was done by hand, but will be automatized in the future. The resulting types of navigation behavior are then coded by reaction parameters of the agents. Due to simplicity of reactive agents the similarity to interactive performance of human drivers cannot be perfect. Machine Learning methods are useful for optimizing the parameters. These methods depend on an adequate measure for the comparison (similarity) of driving styles.

Coding of each MWIs' interactive performance is already highly complex as it is influenced by a great number of factors like individual differences (e.g. personality, skills) or context factors (e.g. adapting to other MWI's navigation style and each MWI's ability to react and adapt to properties of the track). Additionally, in future settings agents will map MWIs' interactive, collective tracking performance which is influenced by hints and restrictions (e.g. asymmetric distribution of MWIs' navigation influence like 80% for one MWI and 20% for the other). Consequently, navigators may change their (individual) behavior according to their experiences with operator's support or restriction. For that, agents need to be provided with a memory and methods for choice and adaptation in future approaches. For this purpose more complex agent architectures are needed which are based on each MWI's internal models of the environment including his predictions of the other MWI's behavior as well as predicting influences by the human operator. Like human MWIs, agents can perform better using some foresight on the track as provided by screen. This could be implemented even for reactive behavior, but it will be more stable by implementing future goals and plans. Again, machine learning methods will be useful.

3.2 Procedure from the psychological perspective

To create artificial agents a framework is needed to decide which types of MWIs' interactive behavior should be implemented. What should an agent be able to do? Which situations will change his (re)actions? Relevant aspects of behavior have to be identified and classified by defining rules for describing, explaining and predicting MWIs' interactive behavior.

Method: As a prerequisite for the development of artificial agents behavior of human MWI-teams needed to be analyzed. 26 data sets from former studies (Nachtwei & Meyer, submitted) using the lab system were analyzed. These data sets comprise individual and

cooperative tracking performance of the two MWIs only (without the influence of an operator): every 39ms deflection of each of their joysticks (each with 50% input to the vehicle) as well as the position of the object was logged among other information. MWIs received different instructions: one MWI was supposed to navigate most quickly (but at the same time accurately), the other was instructed to focus on accurately (but at the same time quickly). Therefore not only their joint tracking-lane, but also their individual tracking-lanes had to be analyzed separately. 11 different trials were completed by the 26 teams (52 MWIs). The first 6 trials served for practising navigation only (MWIs navigated individually first and then cooperatively). The track of trial 7 exhibited characteristics like forks or obstacles for the first time. In trials 8 to 11 MWIs' tracking performance was intervened by an operator. Therefore analysis of MWIs' interactive performance was based on data of trial 7 only, as the artificial agents should map behavior of MWIs only (without the influence of a human operator). In addition behavior was analyzed based on a specific critical navigation situation (navigation at the three forks of trial 7). It was assumed that data gained in these critical situation provided more variance and hence supported an identification of selective types of interactive behavior. Each section around one of the three forks in trial 7 was divided into 10 parts. 26 data set logfiles regarding MWI's interactive behavior in fork situations were transformed to graphics with Matlab for analysis and classification (see figure 3).

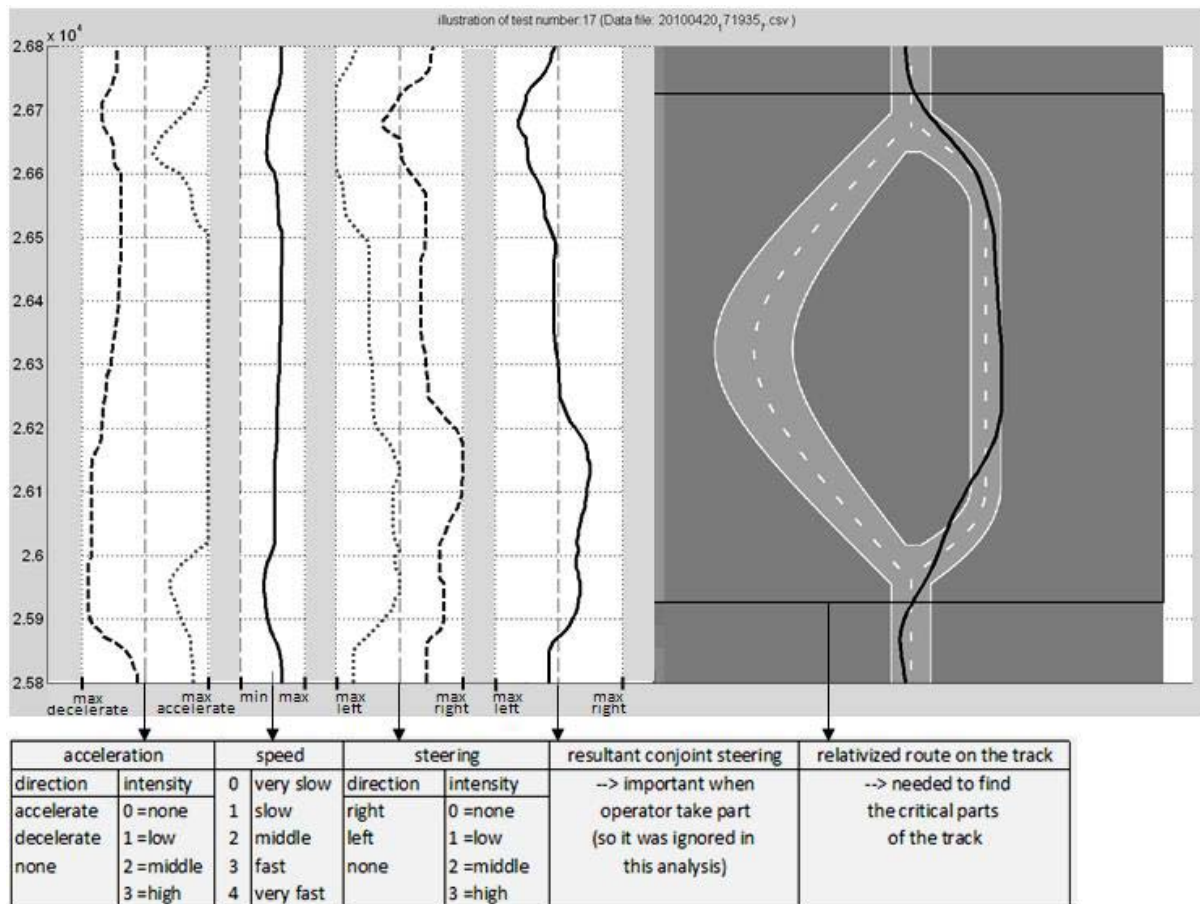


Fig 3: The acceleration-, speed- and steering curve of a data set at a fork & classification system of parameters.

The right part of the graphic shows the track section and the MWIs' joint navigation line approaching the last fork of track 7. The left part of the graphic displays the associated curves of various aspects of MWIs' interactive behavior. Dashed curves represent behavior of MWI 1 (in interaction with MWI 2); dotted curves represent behavior of MWI 2 (in interaction with MWI 1). The very left section shows the acceleration/deceleration curve. As is visible MWI 1 is navigating slowly at most parts of the fork section whereas MWI 2 is navigating with high

speed which represents the instruction they have been given (focus on accuracy vs. speed). Two aspects of their accelerating and decelerating behavior were rated: direction was rated by a 3 point scale: (accelerate, none, decelerate) and strength was rated by a 4 point scale (none, low, middle, high). The second part of the graphic shows a curve of their collective speed. This curve represents the combination (addition) of acceleration and deceleration behavior of both MWI. Collective speed was measured by a 5 point scale (very slow, slow, normal/moderate, fast, very fast). The next two sections of the graphic show each MWI's interactive steering curve. MWIs are navigating in parallel which results in a collective steering curve which is adjusted to the track though displaying a tendency to left (MWI 2) and right respectively (MWI 1). Similar to acceleration the MWIs' steering was rated by a 3 point scale for direction (right, none, left) and by a 4 point scale for strength (none, low, middle, high). The last section of the graphic shows MWIs' resultant conjoint steering. This curve will become important in settings when an intervention of an operator has to be analyzed additionally. Based on these ratings sophisticated interactive behavior patterns of MWIs were found.

Results: Four different patterns of MWIs' individual but interactive (influenced by the other MWI; see section 3.1) behavior were found: (1) *Adapted navigator*: MWI's adjusts the steering to characteristics of the track so deviation of object from track is minimal hence the object is navigated nearly optimally. (2) *Extreme steering navigator*: MWI's steers with maximum deflection alternating extremely from one direction to the other within a short time. This behavior is observable even on straight track sections. (3) *No steering navigator*: there is hardly any steering at all. Even in curves there is only minimal steering taking part when the object is already approaching the verge of leaving the road. (4) *Parallel navigator*: MWI produces a navigation lane comparable to one of an adapted driver but comprises shifts to left or right (see figure 3). The parallel navigator only exists in a team with MWIs who themselves show a tendency to shift either to the right or to the left respectively. A fifth category contained types of behavior deviant from types mentioned above but could not be allocated to one specific category, e.g. MWI jittering while steering for a short or long distance.

Five levels of speed were defined based on observations (very slow, slow, normal, fast, very fast). Regarding the accelerating and decelerating behavior three patterns were found: (1) *Normal*: the MWI is adjusting the speed according to characteristics of track in that he accelerates before curves and forks and accelerates on straight track sections. (2) *None*: the MWI hardly adjusts the speed, maintaining the same speed level all the time. (3) *Deceleration ("decelerator")*: Deceleration object's speed rapidly until object is back on track. This is a temporary category as this behavior only appears when the object has left the road.

From observations of behavior at forks predictions were made using rules ("if... then..."), e.g. if an extreme steering navigator has to decide to drive along the straight or the winding side of a fork then he will always choose the winding one. Thus computer scientists will be able to use these to implement different types of artificial agents. The classification of track sections which contain obstacles is in progress and will be developed based on the same procedure.

3.3 Procedure from the Informatics Perspective

The objective is to create agents modeling typical human navigation behavior of MWI participants. Thus agent's behavior should be complex, i.e. it should not be easily predictable, nor should it be random, i.e. completely unpredictable. Modeling human behavior implies that the agent needs to be enabled to react to various results of his behavior resulting in the interaction with the other MWI. Ideally different types of interactive behavior will be modeled based on observations and clustering MWIs' interactive navigation behavior (see next chapter). In addition agents should be designed in a modular and adaptable way for effortless exchange or expansion, as various navigating behaviors will be implemented and exchanged in the future as the requirements for the experiments change.

Method: Agents are designed to be independent from the implementation of SAM such that they still can be used if the implementation changes. However agents need to be provided with information about SAM. SAM was developed in squeak which is a virtual machine for smalltalk, written itself in smalltalk and highly portable between different platforms. The simulation of the object and tracks are performed by squeak, where all calculations take place, e.g. joystick inputs or controls of the object. Despite that, resources like track files, config files and instructions are accessible from outside the virtual machine.

To classify agents' subtasks the design is based on the classical sense-think-act cycle with each part representing a separate module. Each agent consists of these three parts and the communication module (see upper part of figure 4).

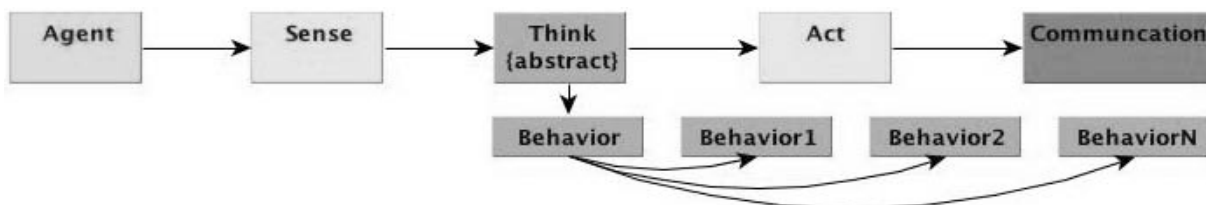


Fig. 4: An agent consisting of sense-think-act and communication modules.

The very first approach was to make each agent a purely reactive one. The reactive agent determines his actual position minimizing its deviance from the track. Thus he steers in track direction with growing force the greater the deviation is. As this agent implements a proportional controller, it can overshoot the setpoint, some oscillating behavior is likely to occur. A related (but not typical) “jittering” behavior could be observed by a human MWI, too (see section 3.2).

To facilitate the option to exchange an agent by another agent with another type of navigation behavior, we used a design pattern named strategy (Gamma, Riehle, Helm, Johnson & Vlissides (2011), which leads to the current state of the architecture. This way different types of behavior can be developed independently, e.g. a simultaneous development of reactive agents and fuzzy technologies. The “think” module is then extended by the different personalities an agent can have.

Results: So far we have implemented a clean structured and modifiable base for our agent, which will allow to test different approaches on how to implement behavior, like reactive

behavior, neural networks, fuzzy logic or others. The first agent is already completed and his behavior is comparable to that of a jittering MWI.

In future approaches the agent will be expanded into a deliberative one, which already shows promising results in traffic simulations (Ehlert & Rothkrantz, 2001). More over results from using fuzzy logic will be analyzed. The various behaviors discovered by the psychologists can be coded and transformed into fuzzy like rules and then be implemented by related agents.

3.4 Discussion

The log file analysis was a first explorative trial to describe behavior of human MWIs. It was based on logfile data sets of two MWIs cooperatively steering an object along a track but focused on their individual "interactive" behavior (as individual behavior was influenced by the other MWI's behavior). It was necessary to choose data which contained interaction between MWIs as interacting (and not single) MWIs should be replaced by agents. The aim was to describe human behavior properly so that agents could be based on these descriptions. To this end we intentionally abstained from identifying causal factors for how or why MWIs developed a special behavior pattern. Description of MWI's was carried out on a phenomenological basis only.

At the current point of implementation, we have not considered issues like agents' reactions on operator's visual and audio hints or learning effects for the MWIs. The reactions on or interaction with operator's suggestions should be analyzed in the future and serve as new input to the agents. This task poses a challenge as MWIs' behavior is determined by a great number of parameters. Therefore it will be difficult to identify which behavior is shown as a reaction on suggestions of the operator, which is shown in reaction to actions of the other MWI and which is just coincidence. Behavior patterns of human MWIs are among other things influenced by individual differences as personality traits or skills. Track characteristics, repetitions of track characteristics and the ability to learn while performing the tracking are additional parameters that influence MWIs' behavior. These aspects will be focused in further work. It should be discussed which aspects are suitably as additional features of agents.

Human MWIs also show an adjustment of their behavior according to behavior of their MWI partner. Several patterns could be observed that were more likely to appear in association with each other (e.g. slowing down navigation when paired with a fast driver (or vice versa), no steering when paired with an extremely deflecting MWI (or vice versa)). It should be explored whether individual differences, e.g. in personality, make a difference in adapting to the other MWI. Furthermore the ability to adjust has to be implemented for agents accordingly. Therefore we are currently working on a strategy pattern, which enables the agent to easily change and choose his behavior during run time.

4 Conclusion

We have reported about an ongoing interdisciplinary project. The testbed SAM is used to examine performance of operators and developers of complex systems as well as performance of SAM's human inhabitants. SAM represents a microworld, which provides unpredictable mechanisms due to social interaction of two human navigators. The situation in the micro

world emerges from the interactions of their navigation strategies. These strategies can be determined by different objectives. But the results of their interfering behavior can be quite different from their objectives. This can force an operator outside of SAM to intervene by related actions, which depend on the facilities provided by the developer of the overall system.

For several reasons, the human navigators are to be replaced by artificial agents. While a simple agent may follow a fixed simple control strategy, more complex agents will try to learn about the strategy of the other agent to get advantages in reaching their individual objectives. Besides the work according to SAM, it will be interesting to learn more about the emergent effects when different agents work together in the microworld of SAM. Up to now, we have identified several types of human navigators by analyzing logfiles by hand.

Related agents are already implemented or will be implemented in the future. After becoming more experienced with the specific settings, we will do type analysis by Machine Learning (e.g. clustering methods). Machine Learning will also be used for optimizing agent behaviors in order to become similar to human navigator strategies.

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