The eXperience Induction Machine: A new paradigm for mixed-reality interaction design and psychological experimentation.

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Introduction

The eXperience Induction Machine (XIM, Fig. 1) located in the laboratory for Synthetic Perceptive, Emotive and Cognitive Systems (SPECS) in Barcelona, Spain, is one of the most advanced mixed-reality spaces available today. XIM is a human accessible, fully instrumented space with a surface area of 5.5x5.5m. The effectors of the space include immersive surround computer graphics, a luminous floor, movable lights, interactive synthetic sonification, whereas the sensors include floor based pressure sensors, microphones and static and movable cameras. In XIM multiple users can simultaneously freely move around and interact with the physical and virtual world.

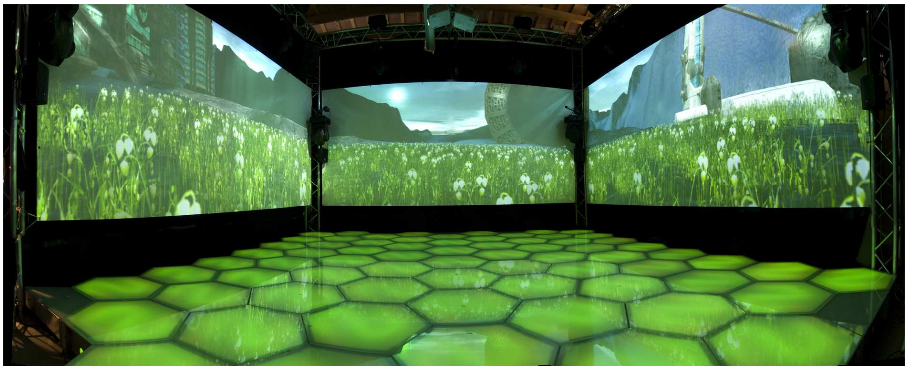

Fig. 1: View into the eXperience Induction Machine

XIM is unique for a number of reasons. Firstly, the space is a true mixed-reality installation, since it does not solely rely on video projections and an audio system as an interface into virtual reality, but is additionally equipped with an active luminous floor and movable lights. Secondly, the architecture of the control system is designed using the large-scale neuronal systems simulation software iqr. Unlike other installations, the construction of XIM reflects a clear, two-fold research agenda: Firstly, to understand human experience and behavior in complex ecologically valid ecologically valid situations that involve full body movement and interaction. Secondly, to build mixed-reality systems based on our current psychological and neuroscientific understanding, and to validate these systems by deploying them in the control and realization of mixed-reality systems.

We will start this chapter by describing XIM's precursor installations including "RoBoser" and "Ada the intelligent" space, built in 2002 for the Swiss national exhibition Expo.02. We then continue with an overview over other multi, and single-user mixed-reality installations such as the Allosphere, highlighting the main differences, and common features.

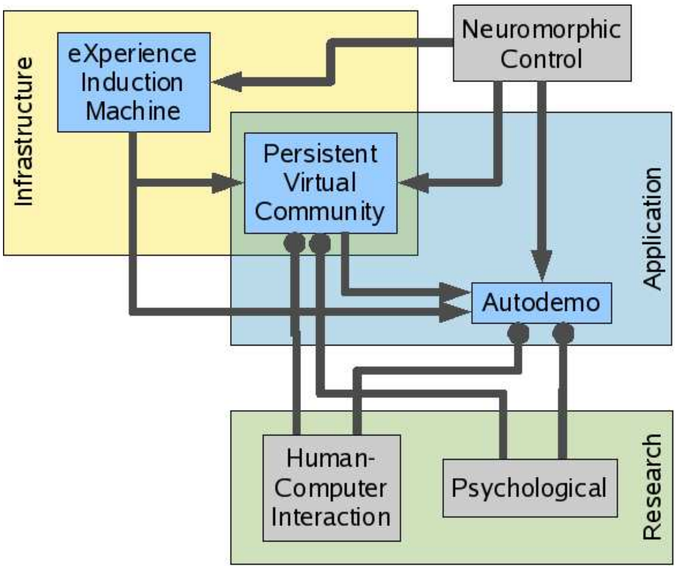

Fig. 2: Relationship between infrastructure and application. The eXperience Induction Machine (XIM) is a general purpose infrastructure for research in the field of psychology and human-artifact interaction. In relation to XIM, the Persistent Virtual Community (PVC) is on the one hand an infrastructure insofar as it provides a technical platform, and on the other hand an application as it is building up on and using XIM. The project "Autodemo", in which users is guided through XIM and the PVC, in turn is an application which is covering aspects of both, XIM and the PVC. In the design and implementation both XIM and the Autodemo, are based on principles and technologies of neuromorphic control. PVC and Autodemo are concrete implementations of research paradigms in the fields of human-computer interaction and psychology.

Subsequently we will lay out the infrastructure of XIM, including a detailed account of the hardware components of XIM, the software architecture, and the overall control system. This architecture includes a multi-modal tracking system, the autonomous music composition system RoBoser, the virtual reality engine and the overall neuromorphic system integration based on the simulator iqr.

We conceive of XIM as a next generation mixed-reality experience and psychological research infrastructure (Fig. 2). To illustrate this approach we will discuss a number of practical applications of XIM: The Persistent Virtual Community (Fig. 2), where entities of different degrees of virtuality can meet and interact, and which is constructed for the investigation of social presence, the interactive narrative “Autodemo” (Fig. 2), and a mixed-reality social interaction paradigm.

XIM's precursor: “RoBoser” and “Ada”

RoBoser: a real-world composition system

The generation of music by machines, and the interaction between musicians and machines, has a broad history and is an active area of current artistic and scientific research efforts. With RoBoser, we addressed the potential of an autonomous interactive composition system in which a real-world artifact (e.g. a robot) and an experimental setup, generate sonic structures in real time without direct human intervention. Thus, RoBoser is not a self-playing device, but a system that produces a sequence of organized sounds that reflect the dynamics of its experience and learning history in the real-world. A system with the capacity of autonomously producing real-time structures out of the interaction between real-world artifacts and their human and nonhuman environments is defined here as a real-world music system [18]. RoBoser consists of two processes, a real-world system and a composition engine. RoBoser maps the states of a real-world system, derived from its sensors and its control model, onto control parameters for its compositional engine. RoBoser’s music engine is Curvasom, an interactive compositional system that generates sonic output using curves to produce perturbations of control structures. This compositional tool operates in real time using a selection of predefined sets of sonic parameters, taking advantage of the MIDI protocol. Curvasom is based on a number of internal heuristics for transforming input states into timed MIDI events — so-called “Sound Functors” — and a set of parametric sound specifications with which the system is seeded. Since 1998, RoBoser has been presented at about 15 public events in different configurations, ranging from interactive techno music in a dance club to the generation of an emotional sonic language for an interactive space. The most ambitious application of the RoBoser framework has been in the interactive exhibition entitled “Ada: The Intelligent Space” [9], where RoBoser provided a musical language for an interactive “soundscape” whose goal was the communication of synthetic emotional states of an artificial environment (Wassermann et al. 2003). The successful use of RoBoser in such a complex application shows the robustness of the paradigm, and demonstrated that RoBoser’s “soundscapes” directly affected visitors’ assessments of their overall experiences in the space and their activity levels [10].

Ada: an intelligence interactive artifact

Ada was an intelligent interactive environment built to foster public debate on the impact of brain-based technology on society, but also to advance the research toward the construction of conscious machines. Ada was conceived as an artificial organism, able to engage visitors in entertaining interactions. Named after Ada Lovelace, author and early pioneer of computer science, this real-world artifact was developed by the Institute of Neuroinformatics (INI) of the ETH and the University of Zurich for the Swiss national exhibition Expo.02 in Neuchâtel. During the Swiss Expo.02, Ada was visited by 560.000 persons during a period of 6 months thus making this installation the largest interactive exhibit ever deployed. The first environment of its kind, Ada was designed like an organism with visual, audio and tactile input, and non-contact effectors in the form of computer graphics, light and sound [10]. Ada had a certain level of coherence and conveyed an impression of a basic unitary sentience. Conceptually, this artifact has been described as an inside out robot able to learn from experience, react in a goal-oriented and situationally dependent way. Ada's behavior was based on a modeled hybrid control structure that includes a neuronal system, an agent based system and algorithmic based processes [9].

Ada was an artificial creature that used multiple modalities to interact, and communicate with its visitors. An interesting aspect of this man-machine interaction was Ada's theatrical and performative behavior that emerged directly from the interaction between the artifact and the audience without dedicated human mediation. A central player in Ada's emergent performance was Ada's interactive sonification that was generated by the synthetic music composition engine RoBoser.

Fig. 3: The "Ada – the intelligent space" at the Swiss National Exhibition Expo.02.

State of the art in human accessible collective virtual and mixed-reality installations

The virtual and mixed-reality spaces existing today can be divided into different categories and areas of operation. The latter includes research in the field of human-computer interaction, rehabilitation, social interaction, education, and entertainment. Depending on their use and function, the installations vary in size, design, number of modalities and their controlling mechanisms. The prototypical 3D virtual environment is the Cave Automatic Virtual Environment (CAVE) demonstrated 1992 [5]. A mixed-reality space, that provides a sophisticated technical implementation is the 3D projecting space Allosphere at the California Nanosystems Institute (CNSI) [15].

While design and usage of these spaces differ, they both excel in having either an advanced technical infrastructure or pursue an ambitious conceptual framework to control the action and user-interaction of the space. Systems dealing with social interactions in mixed-reality include Disney's Pirates of the Caribbean Game [21], the magic carpet from the mixed-reality Laboratory, Nottingham [7] and the kid's room at MIT [3]. Although all these systems provide an interactive mixed-reality environment where a group of people has to behave in a coordinated way, they lack an elaborated framework to observe and quantify human behavior.

Why build such spaces? Epistemological rationale

If psychology is defined as the scientific investigation of mental processes and behavior, it is in the former case concerned with phenomena that are not directly measurable (Fig. 4). These non-measurable phenomena are hence conceptual constructs and referred to "constructs". Typical examples of psychological constructs are "intelligence" and the construct of the "Ego" by Freud [11]. Scientifically, these constructs are defined by their measurement method, a step which is referred to as operationalization.

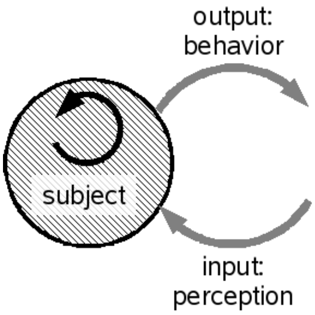

Fig. 4: The field of psychology is concerned with behavior and mental processes, which are not directly measurable. Scientific research in psychology is to a large extent based on drawing conclusions from the behavior a subject exhibits given a certain input.

In psychological research humans are treated as a "black box", i.e. knowledge about the internal workings is acquired by drawing conclusion from the reaction to a stimulus (Fig. 4 input: perception, output: behavior). Behavior, is here defined in a broad sense, and includes the categories of directly and only indirectly measurable behavior. The category of directly observable behavior comprises on the one hand of non symbolic behavior such as posture, vocalization, and physiology, and on the other hand of symbolic behavior such as gesture, and verbal expression. Into category of only indirectly measurable behavior fall the expressions of symbolic behaviors like written text, and non symbolic behaviors such as the history of the web-browsing.

Observation With the above definition of behavior, various study types such as observational methods, questionnaires, interviews, cases studies, and psychophysiological measurements are within the realms of observation. Typically, observational methods are categorized along the dimension of the type of environment in which the observation takes place, and the role of the observer. The different branches of psychology, such as abnormal, developmental, behavioral, educational, clinical, personality, cognitive, social, industrial organizational, or biopsychology, have in common that they are built on the observation of behavior.

Experimental research The function of experimental research is to establish the causal link between the stimulus given to and the reaction of a person. The common nomenclature is to refer to the input to the subject as the independent variable, and to the output as dependent variable. In physics, the variance in the dependent variable is normally very small, and as a consequence, the input variable can be changed gradually, while measuring the effect on the output variable. This allows to test hypothesis that give a quantification of the relationship between independent and dependent variable. In psychology, the variance of the dependent variable is often rather large, and it is therefore difficult to establish a quantification of the causal connection between the two variables. The consequence is that most psychological experiments take the form of comparing two conditions: The experimental condition, where the subject is exposed to a “manipulation”, and the control condition, where the manipulation is not applied. An experiment then allows to draw a conclusion in the form of: a) Manipulation X has caused effect Y, b) in absence of manipulation X effect Y was not observed. To conclude that the observed behavior (dependent variable), is indeed caused by a given stimulus (independent variable), and not by other factors, so called confounding variables, all conditions are kept as similar as possible between the two conditions.

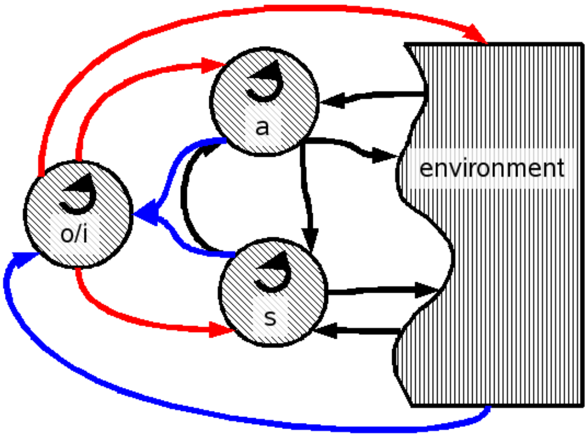

Fig. 5: Systemic view of the configuration in psychological research. S: subject, A: social agent, O/I: observer, or investigator (the implicit convention being that if the investigator is not performing any intentional manipulation, he/she is referred to as an "observer"). The subject is interacting with social agents, the observer, and the environment. For sake of simplicity only one subject, social agent, and observer are depicted, but each of these can be multiple instances. In the diagram red lines indicated possible manipulations, blue lines possible measurement points. The investigator can manipulate the environment, and the social agents of the subject, and record data from the subjects behavior, together with the behavior of other social agents, and the environment.

The concepts of observation and experiment ventilated above can be captured in a systemic view of interaction between the four actors subject, social agent, observer/investigator, and environment (Fig. 5). "Social agent" here means other humans, or substitutes, which are not directly under investigation, but that interact with the subject. Different research configurations are characterized by which actors are present, what and how is manipulated and measured. What distinguishes the branches of psychology is on the one hand the scope (individual – group), and on the other hand the prevalent measurement method (qualitative – quantitative). E.g. in a typical social psychology experimental research configuration, what is of interest is the interaction of the subjective with multiple social agents. The subject is either manipulated directly or via its social interagens.

The requirement of the experimental paradigm to keep all other than the independent variable constant, has as a consequence that experimental research effectively only employs a subset of all possible configurations (Fig. 5): Experiments mostly take place in artificial environment, and the investigator plays a non participating role. This leads to one of the main points of critique of experiments, the limited scope and the potentially low level of generalizability. It is important to keep in mind that observation and experimental method are orthogonal to each other: In every experiment, some type of observation is performed, but not in all observational studies two or more conditions are compared in a systematic fashion.

Mixed and virtual reality as a tool in psychological research

Gaggioli [13] observed on the usage of VR in experimental psychology: “the opportunity offered by VR technology to create interactive three-dimensional stimulus environments, within which all behavioral respondings can be recorded, offers experimental psychologists options that are not available using traditional techniques.” As laid out above, the key in psychological research is the systematic investigation of the reaction of a person to a given input (Fig. 5). Consequently, a mixed-reality infrastructure is ideally suited for research in psychology as it permits to deliver stimuli in a very flexible, yet full controlled way, while precisely recording a person's behavior.

Stimulus delivery In a computer generated environment, the flexibility of the stimulus delivered is nearly infinite (as least the number of pixels on the screen..). This degree of flexibility can also be achieved in a natural environment, but has to be traded with the level of control over the condition. In conventional experimental research in psychology the environment therefore is mostly kept simple and static, a limitation to which mixed-reality environments are not subjected, as they do not have to trade richness with control. Clearly this is a major advantage which allows research which should generalize better from the laboratory to the real-world condition. The same rationale as for the environment is applicable for social interaction. Conventionally, the experimental investigation of social interaction is seen as highly problematic, as the experimental condition is not well controlled: To investigate social behavior, a human actor needs to be part of the experimental condition, yet it is very difficult for humans to behave comparably under different conditions, as it would be required by experimental rigor. Contrary to this, a computer generated Avatar is a perfectly controllable actor, that will always perform in the same way, irrespective of fatigue, mood, or other subjective conditions. A good example of the application of this paradigm is the re staging of Milgram's obedience experiment [26]The eXperience Induction Machine can fulfill both roles; it can serve as a mixed-reality environment and as the representation of a social agent (Fig. 6). Moreover the space can host more than a single participant, hence allowing to expand the advantages of research in a mixed-reality paradigm to the investigation of groups of subjects.

Recording of Behavior To draw conclusions form the reaction of persons to a given stimulus, the behavior, together with the stimulus, need to be measured with high fidelity. In XIM, the spatio-temporal behavior of one or more persons can be recorded together with the state of the environment and virtual social agents. A key feature is that the tracking system is capable of preserving the identity of multiple users over an extended period of time, even if the users exhibit a complex spatial behavior, e.g. by frequently crossing their paths. To record e.g. the facial expression of a user during an experiment in XIM, a video camera is directly connected to the tracking system, thus allowing to videograph the behavior for real-time or post-hoc analysis. Additionally, XIM is equipped with the infrastructure to record standard physiological measures such as EEG, ECG, and GSR from a single user.

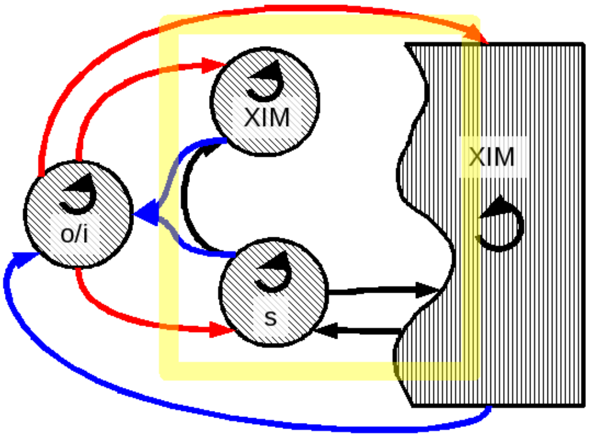

Fig. 6: Systemic view of the role on the eXperience Induction Machine (XIM) in psychological research. XIM is on the one hand a fully controllable dynamic environment, and on the other hand it can substitute social agents. Central to the concept of XIM is that in both roles, XIM has its own internal dynamics (as symbolized by spirals). The yellow line demarcates the visibility as perceived by the subject; whereas XIM is visible as social agent or as environment, the investigator remains invisible to the subject.

Autonomy of the environment A unique feature of XIM is the usage of the large-scale neuronal systems simulator iqr [1] as "operating system". The usage of iqr allows the deployment of neurobiological models of cognition and behavior, such as the Distributed Adaptive Control model [28] for the real time information integration and control of the environment and Avatars (Fig. 6, spirals). A second application of the autonomy of XIM is the testing of a psychological user model in real-time. Prerequisite is that the model is mathematically formulated as is e.g. the "Zurich model of social motivation" [14]. In the real-time testing of a model, predictions about the user's response to a given stimulus are derived from the model, and instantly tested. This allows a testing of the model, and a parameter estimation in a very efficient way.

Challenges of using mixed and virtual reality in psychological research

As in other experimental settings, one of the main issue of the research using VR and MR technology is the generalizability of the results. A high degree of ecological validity, i.e. the extent to which the setting of a study is an approximating the real-life situation under investigation, is not a guarantee, but a facilitator for a high degree of generalizability of the results obtained in a study. Presence, the subjective sense of "being" there in a virtual environment, has two aspects. Firstly, it refers to the place illusion of being in a different than the physical location, and secondly, to the plausibility of the environment and the interactions. It can be assumed, that the latter aspect of presence is directly linked to ecological validity; the more ecologically valid ecologically valid a virtual setting, the higher the level of presence experienced. Hence, vice versa, measures of presence can be used as an indicator of ecological validity. A direct indication that indeed virtual environments are ecologically valid, and can substitute reality to a relevant extent, is the effectiveness of cybertherapy [23].

As a mixed-reality infrastructure, XIM naturally has a higher ecological validity then purely virtual environments, as it comprises “real-world” devices such as the light emitting floor tiles, steerable light, and spatialized sound.

A second shortcoming of VR and MR environments is the limited feedback they deliver to the user, as they predominantly focus on the visual modality. We aim to overcome this limitation in XIM by integrating a haptic feedback device [12]. The conceptual and technical integration is currently underway in the form of a “haptic gateway into PVC”, where users can explore the Persistent Virtual Community not only visually, by also by means of a force-feedback device.

Whereas today's application of VR/MR paradigms is focusing on perception, attention, memory, cognitive performance, mental imagery [13], we strongly believe that the research methods sketched here, will make significant contributions to other fields of psychology such social, personality, emotion, and motivation.

The eXperience Induction Machine

Physical infrastructure

The eXperience Induction Machine covers a surface area of ~5.5 x ~5.5m, with a height of 4m. The majority of the instruments are mounted in a rig constructed from a standard truss system (Fig. 7).

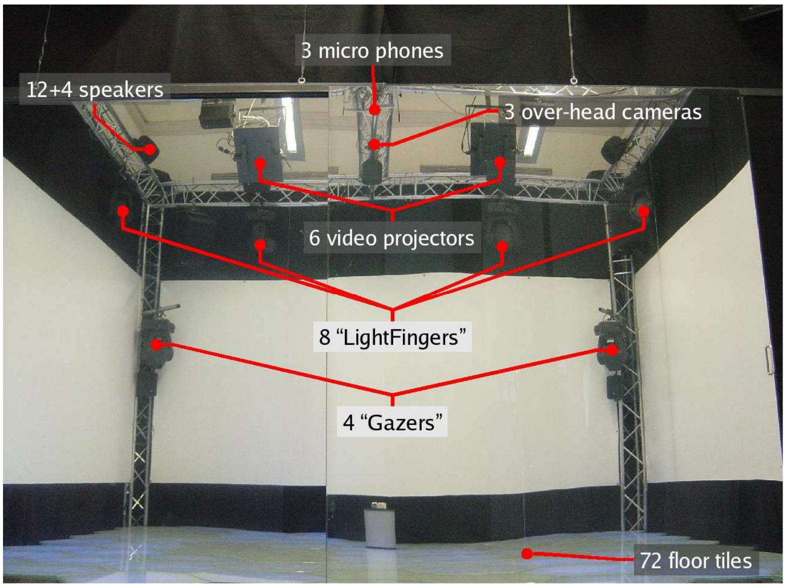

Fig. 7: The eXperience Induction Machine (XIM) is equipped with the following devices: 3 ceiling-mounted cameras. 3 microphones (Audio-Technica Pro45 unidirectional cardioid condenser, Stow, OH, USA) in the center of the rig. 8 steerable theater lights ("LightFingers") (Martin MAC MAC250, Arhus, Denmark). 4 steerable color cameras ("Gazers") (Mechanical construction adapted from Martin MAC250, Arhus, Denmark, camera blocks Sony, Japan). A total of 12 speakers (Mackie SR1521Z, USA) with the corresponding sound equipment provide spatialized sound. The space is surrounded by three projection screens (2.25m x 5m) on which 6 video projectors (Sharp XGA video projector, Osaka, Japan) display graphics. 72 interactive tiles [6] (Custom. Mechanical construction by Westiform, Niederwengen, Switzerland, Interface cards Hilscher, Hattersheim, Germany) constitute the floor of the space. The floor serves a dual purpose: Firstly, each floor tile is equipped with pressure sensors to provide real-time weight information. Secondly. each floor tile incorporates individually controllable RGB neon tubes, permitting to display patterns and light effects on the floor.

System architecture

The development of a system architecture that provides the required functionality to realize a mixed-reality installation such as the Persistent Virtual Community (see below) constitutes a major technological challenge. In this section we will give a detailed account of the architecture of the system that realized the PVC, and "drives" the XIM. We will describe in detail the components of the system and their concerted activity.

XIM's system architecture fulfills two main tasks: On the one hand the processing of signals from physical sensors, and the control of real-world devices, and on the other hand the representation of the virtual world. The physical installation comprises of the eXperience Induction Machine, whereas the virtual world is implemented using a game engine. The virtual reality part comprises of the world itself, the representation of Avatars, functionality such as object manipulation, and the virtual version of XIM. As an integrator the behavior regulation system spawns both, the physical and the virtual world.

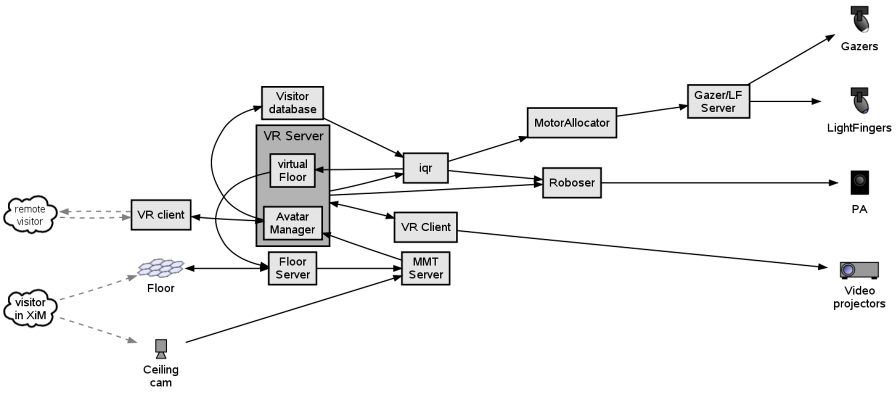

Fig. 8: Simplified diagram of the system architecture of XIM. The representation of the mixed-reality world (“VR Server”) and the behavior control (“iqr”) are the heart of the system architecture. Visitors in XIM are tracked using the pressure sensitive floor and overhead cameras, whereas remote visitors are interfacing to the virtual world over the network by means of a local client connecting to the VR Server.

Design principles

The design of the system architecture of XIM is based on the principles of distributed multi-tier architecture and datagram based communication.

Distributed multi-tier architecture: The processing of sensory information and the control of effectors is done in a distributed multi-tier fashion. This means that “services” are distributed to dedicated “servers”, and that information processing is happing at different levels of abstraction from the hardware itself. At the lowest level, devices such as “Gazers”, and the floor tiles are controlled by dedicated servers. At the middle layer, serves provide a more abstract control mechanism which e.g. allows the control of devices without knowledge of the details of the device (such as its location in space). At the most abstract level the neuronal systems simulator iqr is processing abstract information about users, and regulates the behavior the space

Datagram based communication: With the exception of the communication between iqr and RoBoser (see below), all communication between different instances within the system is realized via UDP connections. Experience has shown that this type of connection-less communication is reliable enough for real-time sensor data processing and device control, while providing the significant advantage of reducing the interdependency of different entities. Datagram based communication avoids deadlocking situations, a major issues in connection oriented communication.

Interfaces to sensors and effectors

The “Floor Server” (Fig. 8) is the abstract interface to the physical floor. The server on the one hand sends the information of the three pressure sensors in each of the 72 floor tiles to the multi-model tracking system, and on the other hand handles request for controlling the light color of each tile. The “Gazer/LF Server” (Fig. 8) is the low level interface for the control of the Gazers and LightFingers. The server is listening on a UDP port and translates requests e.g. for pointing position to DMX commands, which it then sends to the devices via a USB to DMX device (open DMX USB, ENTTEC Pty Ltd, Knoxfield, Australia). The “MotorAllocator” (Fig. 8) is a relay service which manages concurrent requests for Gazers and LightFingers, and recruits the appropriate device, i.e. the currently available device, and/or the device closest to the specified coordinate. The MotorAllocator reads requests from a UDP port, and sends commands via network to the "Gazer/LF Server"

Tracking of visitors in the physical installation Visitors in XIM are sensed via the camera mounted in ceiling, the cameras mounted in the four Gazers, and the pressure sensors in the each of the floor tiles. This information is fed into the multi-model tracking system (MMT, Fig. 8) [19]. The role of the Multi-Modal Tracking Server (MMT Server) is to track individual visitors over an extended period of time, and to send the coordinates and a unique identifier for each visitor to the “AvatarManager” inside the “VR Server” (see below).

Storage of user related information The “VisitorDB” (Fig. 8) serves to store information about physically and remotely present users. A relational database (mySQL, MySQL AB) is used to maintain records of the position in space, the type of visitor, and IDs of the visitors.

The virtual reality server The virtual reality server (“VR Server”, Fig. 8) is the implementation of the virtual world, which includes a virtual version of the interactive floor in XIM, Avatars representing local and remote visitors, and video displays. The server is implemented using the game engine Torque (GarageGames, Inc., OR, USA). In the case of a remote user (“remote visitor”, Fig. 8), a client instance on the user's local machine will connect to the VR server (“VRClient”), and by this way the remote visitor will navigate though the virtual environment. If the user is locally present in XIM (“visitor in XIM”, Fig. 8), the multi-modal tracking system (MMT) sends the information about the position and the identity of a visitor to the VR server. In both cases, the remote and the local user, the "Avatar Manager" inside the VR Server is creating an Avatar, and positions the Avatar at the corresponding location in the virtual world. To make the information about remote and local visitors available outside the VR server, the Avatar Manager is sending the visitor related information to the “visitor database” (VisitorDB, Fig. 8). Three instances of VR clients are used to display the virtual environment inside XIM. Each of the three clients is connected to two video projectors, and renders a different viewing angle (Fig. 1, 7).

Sonification The autonomous reactive music composition system RoBoser (Fig. 8) one the one hand provides sonification of the states of XIM, and on the other hand is used to playback sound effects, such as the voice of Avatars. For the sonification of events occurring in the virtual world, RoBoser directly receives information from the

VR server. The current version of the music composition system is implemented in PureData (http://puredata.info).

System integration and behavior regulation An installation such as the XIM needs an "operating system" for the integration and control of the different effectors and sensors, and the overall behavioral control. For this purposes we use the multi-level neuronal simulation environment iqr developed by the authors [1]. This software provides an efficient graphical environment to design and run simulations of large-scale multi-level neuronal systems. With iqr neuronal systems can control real-world devices — robots in the broader sense — in real-time. iqr allows the graphical on-line control of the simulation, change of model parameters at run-time, on-line visualization and analysis of data. iqr is fully documented and freely available under the GNU General Public License at http://www.iqr-sim.net.

The overall behavioral control is based on the location of visitors in the space as provided by the MMT, and includes the generation of animations for Gazers, LightFingers, and the floor. Additionally a number of states of the virtual world and object therein are directly controlled by iqr. As the main control instance, iqr has a number of interfaces to servers and devices, which are are implemented using the "Module" framework of iqr.

The two iqr modules "*Gazer Control*" and the "*LightFinger Control*" are both sending requests to the "Motor Allocator" for controlling the Gazers, and the LightFingers respectively. The "LightFinger Control" module allows specifying the position at which LightFingers are pointing, and the color of the light as a hue value. For the Gazers, currently only pointing position can be controlled. Both modules allow choosing between allocating a single device or all devices to the specified coordinate. The "*DB Access*" module is establishing a connection to the visitor database, and represents the position of each visitor in XIM as the activity in a group of neurons. Via the "Torque Client" module iqr is receiving information from the VR server. In the case of the Autodemo (see below), this information includes the position of the virtual guide Ava, and information related to the football game, such as the position of the ball and collision between players and the ball. By default, the state of each floor tile is directly controlled by iqr using the "Floor Controller" module. The commands controlling the floor tiles are not directly sent to "FloorServer", but routed trough the "VR Server". There reason for this is that when games are being played, such as "football", the game logic is realized in the VR server, as the game is relying on a physics engine e.g. for collision detection between players and the ball. To ensure coherence between the virtual and the physical floor the control signal therefore has to be sent from the VR Server to the "FloorServer". Via the "*PDSendOsc*" module data oriented information such as the center of mass of visitors, and timing is send to RoBoser. The communication implemented in this module is based on the Open Sound Control (OSC) (http://opensoundcontrol.org/). The "Torque Remote Control" module allows iqr a fine grain control over different aspects of the virtual environment and entities in the environment such as Avatars. The interface between iqr and Torque can have one three forms. Firstly, "maps" are representation of spatial data, this means that the position (x and y) of an active cell in a population of neurons is translated into a coordinate. With respect to Avatars, maps are used to control the move destination and behavioral aspects such as pointing to a specific location. In the control of the virtual cameras, maps are used to define the position, and the orientation of the cameras in space. Secondly, single neurons are encoding "discrete" value. This interface type is used to trigger animations of Avatars, to change the shape of Avatars, to switch to a different camera views, and to start the playback of videos in the virtual world. The third form of interface is the "scalar" representation. Here a value is represented by the membrane potential of a neuron. This representation is used e.g. to set move speed and scale of Avatars, and to define the move speed of virtual cameras.

XIM as a platform for psychological experimentation

The Persistent Virtual Community

One of the applications developed in XIM is the Persistent Virtual Community (PVC, Fig. 2). The PVC is one of the main goals of the PRESENCCIA project [27], which is tackling the phenomenon of subjective immersion in virtual worlds from a number of different angles. Within the PRESENCCIA project, the PVC serves as a platform to conduct experiments on presence, in particular social presence in mixed-reality. The PVC and XIM provide a venue where entities of different degrees of virtuality (local users in XIM, Avatars of remote users, fully synthetic characters controlled by neurobiologically grounded models of perception and behavior) can meet and interact. The mixed-reality world of the PVC consists of the Garden, the Clubhouse, and the Avatar Heaven (Fig. 9). The Garden of the PVC is a model ecosystem, the development and state of which depends on the interaction with and among visitors. The Clubhouse is a building in the Garden, and houses the virtual XIM. The virtual version of the XIM is a direct mirror of the physical installation: any events and output from the physical installation are represented in the virtual XIM and vice versa. This means e.g. that an Avatar crossing the virtual XIM, will be represented in the physical installation as well. The PVC is accessed either through XIM, by way of a Cave Automatic Virtual Environment (CAVE), or via the Internet from a PC (Fig. 9).

The aim of integrating XIM into PVC is the investigation of two facets of social presence. Firstly, the facet of the perception of the presence of another entity in an immersive context, and secondly, the collective immersion experienced in a group, as opposed to being a single individual in a CAVE. For this purpose XIM offers a unique platform, as the size of the room permits the hosting of mid-sized groups of visitors. The former type of presence depends on the credibility of the entity the visitor is interacting with. In the XIM/PVC case the credibility of the space is affected by its potential to act and be perceived as a sentient entity and/or deploy believable characters in the PVC that the physically present users can interact with. In the CAVE case, the credibility of the fully synthetic characters depends on their validity as authentic anthropomorphic entities. In case of XIM this includes the preservation of presence when the synthetic characters transcend from the virtual world into the physical space, i.e. when their representational form changes from being a fully graphical humanoid to being a lit floor tile

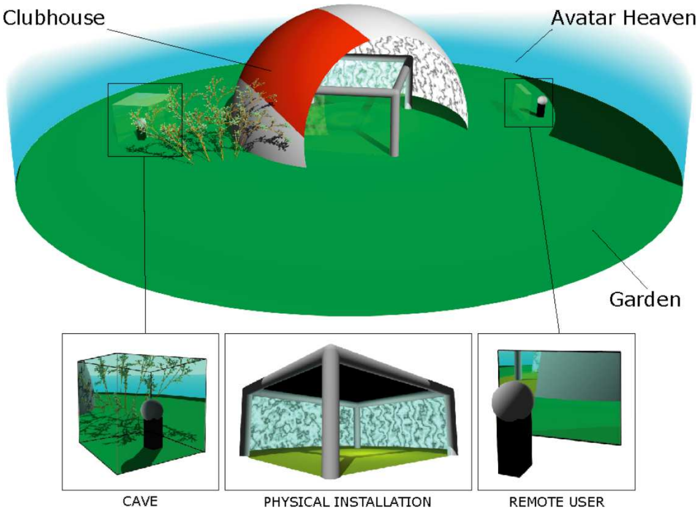

Fig. 9: Topology of the Persistent Virtual Community (PVC). The mixed-reality world consists of the Clubhouse, the Garden, and the Avatar Heaven. The virtual counterpart of the physical installation eXperience Induction Machine (XIM), is located inside the Clubhouse. Users can either access through the physical installation, or a Cave Automatic Virtual Environment (CAVE), or via the Internet from a PC (remote user).

A space explains itself: The "Autodemo"

A fundamental issue in presence research is how we can quantify "presence". The subjective sense of immersion and presence in virtual and mixed-reality environment has thus far mainly been assessed through self-description in the form of questionnaires [24], [29]. It is unclear however to what extent the answers that the users provide actually reflect the dependent variable, in this case "presence", since it is well know that a self-report based approach towards human behavior and experience are error prone. It is therefore essential to establish an independent validation of these self-reports. Indeed, some authors have used real time physiology [4], [8], [20], [25] for such a validation. In line with previous research, we want to asses whether the reported presence of by user correlates with an objective measures such as those that assess memory and recollection.

Hence, we have investigated the question whether more objective measures can be devised that can corroborate subjective self-reports. In particular we have developed an objective and quantitative recollection task that assess the ability of human subjects to recollect the factual structure and organization of a mixed-reality experience in the eXperience Induction Machine. In this experience – referred to as "Autodemo" – a virtual guide explains the key elements and properties of XIM.

The Autodemo has a total duration of is 9min 30sec, and is dived into four stages:

“sleep”, “welcome”, “inside story”, and “outside story”. Participants to the Autodemo are led through the story by a virtual guide, which comprises a pre-recorded voice track (one of the authors) that delivers factual information about the installation, and an Avatar that is an anthropomorphic representation of the space itself. By combining a humanoid shape and an an-organic texture, the Avatar of the virtual guide is deliberately designed to be a hybrid representation.

After exposure to the Autodemo, the users' subjective experience of presence was assessed in terms of media experience (ITC-Sense of Presence Inventory – [17]). As a performance measure, we developed a XIM specific recall test that specifically targeted the user’s recollection of the physical organization of XIM, its functional properties and the narrative content. This allowed us to evaluate the correlations between the level of presence reported by the users and their recall performance of information conveyed in the “Autodemo” [2].

By evaluating the users’ subjective experience in the mixed-reality space, we were able to identify a positive correlation between the presence engagement scale and factual recall. Moreover, our results indicated that information conveyed in the interactive parts of the Autodemo was better recalled than those that were conveyed at the moments that the subjects were passive. We believe that the correlation between recall performance and the sense of presence identified opens the avenue to the development of a measure of presence that is more robust, and less problematic than the use of questionnaires.

Cooperation and competition: Playing football in mixed-reality

Although the architectures of mixed-reality spaces become increasingly more complex, our understanding of social behavior in such spaces is still limited. In behavioral biology sophisticated methods to track and observe the actions and movements of animals have been developed, while comparably little is known about the complex social behavior of humans in real and mixed-reality worlds. By constructing experimental setups where multiple subjects can freely interact with each other and the virtual world including synthetic characters, we can use XIM to observe human behavior without interferences. This allows us to gain knowledge about the effects and influence of new technologies like mixed-reality spaces on human behavior and social interaction. We addressed this issue by analyzing social behavior and physical actions of multiple subjects in the eXperience Induction Machine. As a paradigm of social interaction we constructed a mixed-reality football game in which two teams of two players had to cooperate and compete in order to win [16]. We hypothesize that the game strategy of a team, e.g., the level of intra-team cooperation while competing with the opposing team, will lead to discernible and invariant behavioral patterns. In particular we analyzed which features of the spatial position of individual players is predictive of the game's outcome.

Our results show that winners and losers employ a different strategy as expressed in the inter-team-member distance. This difference in distance patterns can be understood as a difference in the level of cooperation within a team or the way the team members regulate their behavior to compete with the opposing team.

Conclusion and outlook

In this chapter we gave a detailed account of the immersive multi-user space eXperience Induction Machine XIM. We set out by described XIM's precursors Ada and RoBoser, and followed with a description of the hardware and software infrastructure of the space. Three concrete applications of XIM were presented: The Persistent Virtual Community, a research platform for the investigation of (social) presence; the "Autodemo", an interactive scenario in which the space is explaining itself that is used for the researching the empirical basis of the subjective sense of presence; and finally, the application of XIM in the quantification of collaboration and competition based on spatio-temporal behavior of users in a mixed-reality variation of the classical computer game pong. The methodological concepts proposed here provide examples of how we can face the challenge of quantitatively studying human behavior in situations that have thus far eluded systematic study.

We have tried to elaborate in some detail the epistemological rational behind the construction of a mixed-reality space such as XIM. We did so because we are convinced that mixed and virtual reality infrastructures such as XIM represent the psychological research platform of the future. Part of this process will be that research is moving beyond the currently predominant investigations of human-computer interaction, which focuses on the media itself, into a wider investigation of the human psyche, e.g. the fields of personality, motivational and emotional psychology.

Ecological validity is often seen as one of the pivotal aspects, and short comings of current VR and MR environments. Yet the ecological validity will undoubtedly increase with the advancement in the field of computer graphics, and development of new and better feedback devices. What is frequently neglected though, is the importance of plausibility in the interaction of the user with the virtual environment and virtual actors inhabiting it. We believe that a high level of plausibility can only be achieved by employing bio-inspired AI system for the control of environments and virtual characters, equipping them with an appropriate level of autonomy. This is the rational why we are using the large-scale neuronal system simulator as an “operating system” in XIM. It is in this vein, that we see our engagement in the field of interactive narratives, and performance arts, like the interactive real-time performance re(PER)curso staged in 2007 [22].

References

1. Bernardet, U., Blanchard, M., and Verschure, P.F.M.J. IQR: a distributed system for real-time real-world neuronal simulation. *Neurocomputing 44-46*, (2002), 1043—1048.
2. Bernardet, U., Inderbitzin, M., Wierenga, S., Väljamäe, A., Mura, A., and Verschure, P.F.M.J. Validating presence by relying on recollection: Human experience and performance in the mixed reality system XIM. *The 11th Annual International Workshop on Presence, October 25-27*, (2008), 178-182.
3. Bobick, A.F., Intille, S.S., Davis, J.W., et al. The KidsRoom: A Perceptually-Based Interactive and Immersive Story Environment. *Presence: Teleoperators & Virtual Environments 8*, 4 (1999), 369-393.
4. Brogni, A., Vinayagamoorthy, V., Steed, A., and Slater, M. Variations in physiological responses of participants during different stages of an immersive virtual environment

experiment. *Proceedings of the ACM symposium on Virtual reality software and technology*, ACM (2006), 376-382.

5. Cruz-Neira, C., Sandin, D.J., and DeFanti, T.A. Surround-screen projection-based virtual reality: the design and implementation of the CAVE. *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*, ACM (1993), 135-142.
6. Delbrück, T., Whatley, A.M., Douglas, R., Eng, K., Hepp, K., and Verschure, P.F.M.J. A tactile luminous floor for an interactive autonomous space. *Robot. Auton. Syst. 55*, 6 (2007), 433-443.
7. D. Stanton, V.B. and Pridmore, T. Classroom collaboration in the design of tangible interfaces for storytelling. *CHI '01: Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2001), 482—489.
8. Emmelkamp, P.M. and Felten, M. The process of exposure in vivo: cognitive and physiological changes during treatment of acrophobia. *Behaviour Research and Therapy 23*, 2 (1985), 219-23.
9. Eng, K., Baebler, A., Bernardet, U., et al. Ada - Intelligent Space: An artificial creature for the Swiss Expo.02. *Proceedings of the 2003 IEEE International Conference on Robotics and Automation (ICRA 2003), Sept. 14-19*, (2003).
10. Eng, K., Douglas, R., and Verschure, P.F.M.J. An interactive space that learns to influence human behavior. *Systems, Man and Cybernetics, Part A, IEEE Transactions on 35*, 1 (2005), 66-77.
11. Freud, S. *Das Ich und das Es: Metapsychologische Schriften.* Fischer (Tb.), Frankfurt, 1992.
12. Frisoli, A., Simoncini, F., Bergamasco, M., and Salsedo, F. Kinematic Design of a Two Contact Points Haptic Interface for the Thumb and Index Fingers of the Hand. *Journal of Mechanical Design 129*, 5 (2007), 520-529.
13. Gaggioli, A. Using Virtual Reality in Experimental Psychology. In *Towards Cyberpsychology.* IOS Press, Amsterdam, 2001, 157-174.
14. Gubler, H., Pa□rath, M., and Bischof, N. Eine Ästimationsstudie zur Sicherheits- und Erregungsregulation während der Adoleszenz. *Untersuchungen zur Systemanalyse der sozialen Motivation (III) 202*, (1994), 95—132.
15. Höllerer, T., Kuchera-Morin, J., and Amatriain, X. The allosphere: a large-scale immersive surround-view instrument. *Proceedings of the 2007 workshop on Emerging displays technologies: images and beyond: the future of displays and interacton*, ACM (2007), 3.
16. Inderbitzin, M., Wierenga, S., Valjamae, A., Bernardet, U., and Verschure, P.F.M.J. Social Cooperation and Competition in the Mixed Reality Space eXperience Induction Machine. *The 11th Annual International Workshop on Presence, October 25-27*, (2008), 314-318.
17. Lessiter, J., Freeman, J., Keogh, E., and Davidoff, J. A Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators & Virtual Environments 10*, 3 (2001), 282-297.
18. Manzolli, J. and Verschure, P.F.M.J. Roboser: A Real-World Composition System. *Computer Music Journal 29*, 3 (2005), 55-74.
19. Mathews, Z., Bermúdez i Badia, S., and Verschure, P.F.M.J. A Novel Brain-Based Approach for Multi-Modal Multi-Target Tracking in a Mixed Reality Space. *Proceedings of 4th INTUITION International Conference and Workshop on Virtual Reality 2007*, (2007).
20. Meehan, M., Insko, B., Whitton, M., and Frederick P. Brooks, J. Physiological measures of presence in stressful virtual environments. *Proceedings of the 29th annual conference on Computer graphics and interactive techniques*, ACM (2002), 645-652.
21. Mine, M. Towards virtual reality for the masses: 10 years of research at Disney's VR studio. *Proceedings of the workshop on Virtual environments 2003*, ACM (2003), 11-17.

22. Mura, A., Rezazadeh, B., Duff, A., et al. re(PER)curso: an interactive mixed reality chronicle. *ACM SIGGRAPH 2008 talks*, ACM (2008), 1-1.
23. Riva, G., Botella, C., Legeron, P., and Optale, G. *Cybertherapy: Internet and Virtual Reality As Assessment and Rehabilitation Tools for Clinical Psychology and Neuroscience*. IOS Press, 2004.
24. Schubert, T.W. The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Zeitschrift für Medienpsychologie 15*, 2 (2003), 69-71.
25. Slater, M. How Colorful Was Your Day? Why Questionnaires Cannot Assess Presence in Virtual Environments. *Presence: Teleoperators & Virtual Environments 13*, 4 (2004), 484-493.
26. Slater, M., Antley, A., Davison, A., et al. A Virtual Reprise of the Stanley Milgram Obedience Experiments. *PLoS ONE 1*, 1 (2006), e39.
27. Slater, M., Frisoli, A., Tecchia, F., et al. Understanding and Realizing Presence in the Presenccia Project. *Computer Graphics and Applications, IEEE 27*, 4 (2007), 90—93.
28. Verschure, P.F.M.J., Voegtlin, T., and Douglas, R. Environmentally mediated synergy between perception and behaviour in mobile robots. *Nature 425*, (2003), 620-624.
29. Witmer, B.G. and Singer, M.J. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators & Virtual Environments 7*, 3 (1998), 225-240.

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