Acting Beyond Reality – The Role of Schemata in Mixed-Reality Super-Natural Interaction

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Abstract: Mixed-Reality (MR) and immersive virtual environments (VE) enable the use of interaction techniques (IT)s that exceed the capabilities of the real world. In this short paper, we present the Schemata-Based Interaction Cycle (SBIC), a composite model based on different perspectives on human-computer interaction. The SBIC is currently under development and can be used as foundation to analyzing super-natural (SN)-ITs.

Keywords: Mixed Reality, Virtual Environments, Interaction Techniques and Metaphors, Models for Interaction, Interaction Design, Schemata, Action Regulation

1 Introduction

The idea of an *Ultimate Display* [Sut65], a device that is capable of exactly reproducing reality in a computer-generated VE, has been a guidance in MR research for decades. But VEs do also allow the implementation of super-natural interaction techniques (SN-IT)s, which allow a user to perform tasks that are not possible in reality. SN-ITs provide a special case in the domain of interaction research as actions and observations of a user may contradict our real-world experience, action sequences cannot necessarily be deduced from previous experience and novel and unexpected responses from the VE have to be learned. The SBIC is a model for action-regulation theory for SN-ITs in MR which can be used to analyze and discuss concepts and important factors for applying SN-ITs. The SBIC aims at providing a view on diverse questions regarding the design of SN-ITs in MR. How can underlying mechanism of SN interaction systematically be described to find differences and similarities? What are factors that lead to a good design and which factors lead to the failure of an IT? Why can we easily use ITs that contradict our knowledge of the real world?

The remainder of this paper structures as follows. First, we provide an overview of research regarding SN-ITs and the general use of schemata as concept in human-centered research. Then, we introduce the schemata interaction cycle, a theoretical model that is constructed from different perspectives on action regulation and design of human-computer interaction. From the model, we deduce the concept of schema decomposition and apply it in the field of designing SN interaction in MR. Finally, we discuss the current state of our research and conclude with an outlook on future activities and implications.

2 Related Work

SN-ITs in MR applications haven been researched for decades. MR environments do not only allow us to recreate reality, but also extend our perception and possibilities for interaction. Leaving behind the familiar environment to benefit from technology [Mad00] introduces unique challenges to interaction research. This field of research is not clearly structured and concurrent terms are used to describe interaction techniques and metaphors that enable users to exceed the limitations of the real world. Typical terms to describe this form of interaction are 'magic' [VCWP96, CGVT03, YLO17, Ave08], 'beyond-reality' [AHLF22], 'super/hyper-natural' [NB15, DLSG18, KLD+16, MGB+18], 'super-powers/-human' [RBB13, KML+17, WAC+21, SH21]. Some models have been proposed for classification of terms [NB15, DLSG18, WAC+21]. Jacob introduced the general concept of 'Reality-Based Interaction' to describe tradeoffs between reality-coherent experience and skills and enhanced properties such as efficiency and expressive power [JGH+08]. Abtahi et al. present an extensive literature research and provide a simplified model for action control in sensorimotor tasks in their 'Beyond Being Real'-framework [AHLF22]. A different perspective on SN interaction is the identification of inspiration and design patterns [SH21, MSS14]. SN-ITs can be based on commonly known super heroes [WAC+21, KLD+16, PBWI96]. Other inspiration can be drawn from magic [YLO17, Gla19] and fairytales or folklore [Ave08, PST+96, MSRJ19].

The basis of the presented SBIC-model in this paper is the utilization of schemata in our decision making and action regulation. Schemata (sometimes also 'schemes'. Greek for 'image') can be described as organized and related patterns of thinking and acting that provide templates for understanding and acting upon the world around us [IN80, Arb92]. Generally speaking, an action takes place between a subject and the objective environment to produce an intentional outcome by following a planned sequence of hierarchical operations [ZF18]. Schemata are flexible and adapt to account for new experiences which do not fit into existing structures [Bar32], or they are reinforced when experiences match the existing cognitive model [Pia03]. They play an important role in cognitive and behavioral sciences and related domains of research [Arb92]. The concept of schemata can be applied to form models in different domains: For example, in psychology, schemata that describe the self and the environment can be categorized into different categories which is used as model for analysis and therapy [YKW06]. In computational cognitive architectures, models often implement schema-related abstract structures to represent procedural or factual knowledge of a system, for example as 'productions', 'rules' or 'chunks' in ACT-R [RTO19] and in SOAR [LNR87]. Schemata are also encountered in cognitive linguistics as a result of our interaction with our environment in form of 'image schemes' [Lak90] or 'innate ideas' [Cho67]. Various models for human action-cycles exist. They typically show a cycle with variants of four phases: *planning*, *acting*, *observation* and *evaluation* (e.g., [RFS97, Nor88, Kri05, AHBM01, ZF18]). Other models are based on the idea of interaction concepts (e.g., [Nor88, Ben93]). A model for interaction techniques which uses schema theory as theoretical foundation and combines these both perspectives has, to our knowledge, not been published, yet.

3 The Schemata-Based Interaction Cycle

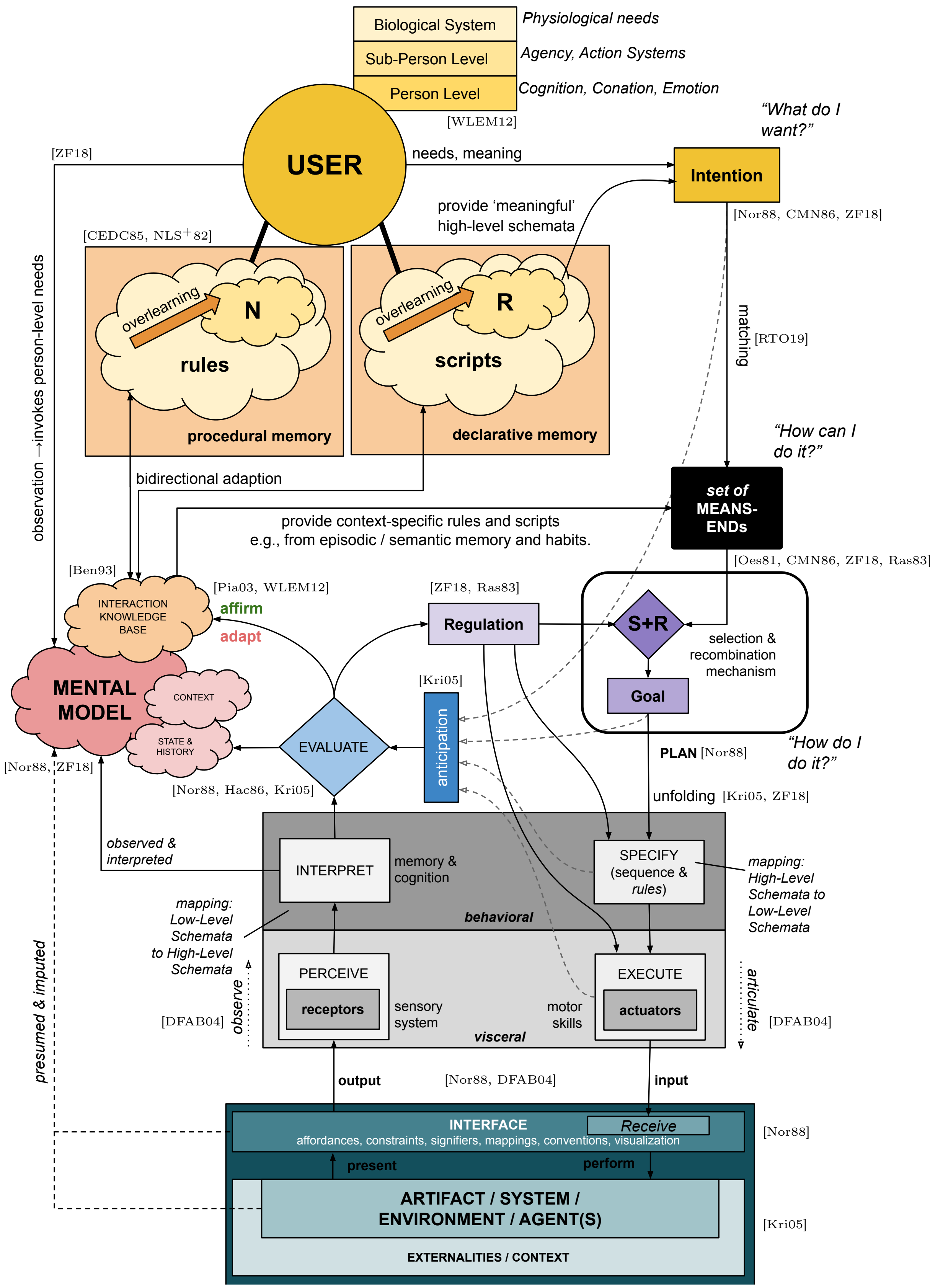

Figure 1: The SBIC as composite model for human-computer interaction. Influential works and adapted models are referenced within the diagram at the respective location.

To allow for an analysis of SN-ITs, the SBIC is presented in this chapter (see Figure 1). It has been developed by merging different views on and models for interaction to form an extensive – but not complete – model for human-computer interaction. The influence of previous work from the fields of human-computer interaction, psychology, cybernetics and design are referenced within Figure 1 and also in the text at their first appearance to allow conferring aspects of the SBIC to existing constructs. In psychology, the human memory is typically divided into procedural memory, which contains action patterns, and declarative memory, which contains semantic facts and episodic memories [GNW03, CEDC85, DK15]. Schemata as part of the memory system also be divided into practical skills (called 'rules' in this paper) that are contained in the procedural memory, and factual knowledge (called 'scripts' in this paper), that are found in the declarative memory. The SBIC starts with a user who interacts with a computer system, for example in a VE, and observes the system. By comparing the system status to the high-level user needs cognition, conation and emotion or lower level needs (cf. [WLEM12] p. 34) and finding a deviation or need for action, the user forms a *intention* for interaction to achieve a desired state in the future [ZF18] ("What do I want?"). From the *intention*, the user matches a *set of means-ends* that provides a selection of scripts and related rules from the *Interaction Knowledge Base* [Ben93] (IKB) of the mental model of the system ("How can I do it?"). The IKB contains (possibly falsely believed) interaction schemata that may lead to a specific outcome in a given context. When a user is confronted with a VE for the first time, the IKB adapts scripts from previously experienced similar applications as 'weak' candidates of what may be possible in an unfamiliar VE. The system can also be designed to display a system-specific *interface* that provides cues and restrictions on what can be *performed* (cf. [Nor88]). By applying different scripts and observing the outcome, the user builds and constantly refines the IKB for a specific VE to contain 'strong' candidates for interaction. Rules and scripts can be overlearned to facilitate application. Overlearing has been used as term in psychology to describe a training of a skill beyond the point of perfect execution [Ebb13, DJ96], for example, recalling a sequence of numbers without error . It has been shown that overlearning has a positive effect on future application and automation of skills [NLS+82]. In the SBIC, scripts and rules can be overlearned and build two distinct sets of overlearned schemata. N describes the set of overlearned 'practical skills', R is the set of overlearned 'facts' of an individual user. As part of the procedural memory, rules in N are executed in an subconscious and intuitive way and explanation can in some cases be difficult (for example, how to ride a bike or how to run), while scripts in R are typically actively retrieved (for example, reciting a poem from memory or remembering a date). In a selection (cf. [CNM83] p. 139) and recombination process the most promising candidate for interaction is determined from the *set of means-ends* as *goal* [Nor88, CMN86] of an instrumental action (cf. [WLEM12] p. 35) ("What do I do?"). *Selection* describes a simple lookup, how a specific goal has been achieved before and applying scripts in the same way. *Recombination*, on the other hand, is the generation of a sequence of possibly parallel actions, that may lead to a desired result (see Figure 2). This process is complex as

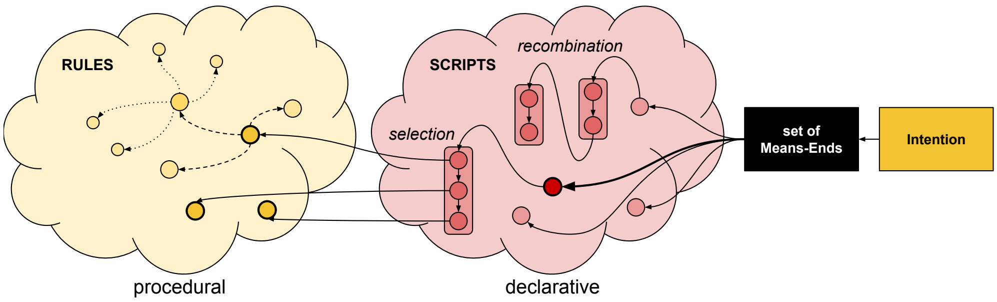

Figure 2: The process of selection or recombination of scripts from the set of means-ends to reach a goal. The set of means-ends points to different script that are related to the intention. Scripts point to a sequence of sub-scripts and hierarchical rule-sequences, respectively.

it is influenced by many internal and external factors and can be described as an application of "meta-cognitive heuristics" [ZF18]. The goal unfolds (cf. [Kri05] p. 85) by *specifying* a sequence of hierarchical actions [ZF18], which are *executed* (cf. [Nor88]) to *articulate* them as *input* to the system (cf. [DFAB04] p. 128). From a psychological perspective, the *specification* is conducted on a behavioral level and the *execution* is carried out on a visceral level [Nor88]. *High-level schemata* are decomposed into a sequence of *low-level schemata* which can be executed in a planned order or in parallel (cf. [Oes81] p. 11). The system receives these *inputs* and translates the user's commands to a system-specific reaction. The reaction is *presented* to the user, which may produce an output that can be sensed by the user, such as audio or visual elements, or in a indirect and subtle way without further evidence of produced effects. Now, the user *perceives* (on the visceral level) the system's feedback and *interprets* the result (on the behavioral level) [Nor88]. Again, schemata can be applied to interpret a system response more easily. This interpretation is compared to *anticipations* (cf. [Kri05]) on different levels (From highest to lowest: What did the user want initially (*intention*)? Does the selected means-end script lead to the desired outcome (*goal*)? Is the application of schemata done correctly (*specification*)? Did a specific rule produce the expected outcome in this context (*execution*)? On a lower level of evaluation, a continuous *regulation* bypasses the high-level conscious cycle of forming a goal to control the application of rules in a mostly subconscious and automated way or on a semi-conscious level [ZF18], for example on the 'sensomotoric regulation-level' and on the 'perceptive-conceptual'-level [Hac86]. On the higher 'intellectual' levels (cf. [FS99] p. 48), the approach of reaching a goal is re-evaluated and corrected, if necessary. In case of an intended system reaction the IKB is strengthened and rules and scripts are *affirmed*, whereas, if the system reaction deviates from the expected behavior, the *mental model* needs to be updated by *adapting* the model to evaluation (cf. [Pia03]). A deviation from expected behavior can be described as 'disruption' that leads to a transition from the 'reliance' phase of using a system to an 'exploration' of the system-specific functionalities [Kri05]. The IKB can also be interpreted as 'background' that allows inferencing scripts for interaction by forming abductive hypotheses (cf. [WLEM12] p.31), which can also be applied in other, similar VEs.

4 Schema Decomposition

The SBIC can be used as underlying theoretical construct to perform a schemata analysis on a specific IT by decomposing it into individual schemata. Schemata analysis is used in a similar way as well-known models in human-computer-interaction such as CPM-GOMS [GJA92] but sets its focus on analyzing the application of re-usable schemata in interaction. Schemata are constructed in a hierarchic way with multiple layers of sequential sub-goals [Oes81] and a tree-like structure of related actions [SKT18]. As first step after forming an intention, a form of means-ends analysis is performed, either by selection a existing script that matches the intention (*schema selection*), or by recombining known schemata into a new sequence (*schema recombination*). In recombination, schemata are reusable and flexible and can be utilized in a modular way to form a new composite schema. They can also be rearranged within the sequence to change the order of execution. New schemata can be inserted into a sequence with modifications (*schema adaption*) or without modifications (*schema integration*) to account for influencing factors in a specific context. It is also possible to learn new interactions by generating an entirely new schema (*schema development*) when a goal cannot be reached by using existing schemata, which is facilitated by adapting similar schemata. Active schemata can be one-time actions (e.g., pressing a button) or continuous actions (e.g., pressing and holding a button). Reception schemata allow a fast interpretation of perceived properties (e.g., on a lower level, using red colors for warning or, on a higher level, using culture-dependent symbols). Schemata can rely on *generic* rules that are re-mapped to a system-specific action (for example, a button that invokes some function). Finally, all rules rely on specific user resources as actuators (e.g., motor skills) or receptors (visual and auditory system).

5 Application in Super-Natural Interaction in Mixed Reality

VEs and MR-environments allow novel ways of interaction that are not possible in the real world such as flying, walking through and on walls, x-ray or information-enhanced vision. To utilize a unfamiliar SN-IT, schemata for interaction have to be developed by a user. In the first step of the SBIC, the initial *goal* formation, the knowledge of SN-ITs provides new and real-world-independent *meaningful schemata* of what can possibly done in a VE. These scripts can contradict other reality-based scripts of R and are only valid in this special context. Considering the task of exploring a VE, for example, a user may want to hover in a certain height above the ground to have a better overview of surroundings [FKMK98, WO90], but only if he or she knows that and how schema can be applied in this specific VE. On the other hand, SN-ITs can also provide novel ways to reach real-world-coherent goals. For instance, locomotion can often be achieved by walking, but also by using a teleportation technique. The possibility of applying a SN-IT has to be communicated to the user and internalized by him or her to enable the matching between the *goal* and the *set of means-ends*. As the input for a specific technique can be implemented arbitrarily, the successful

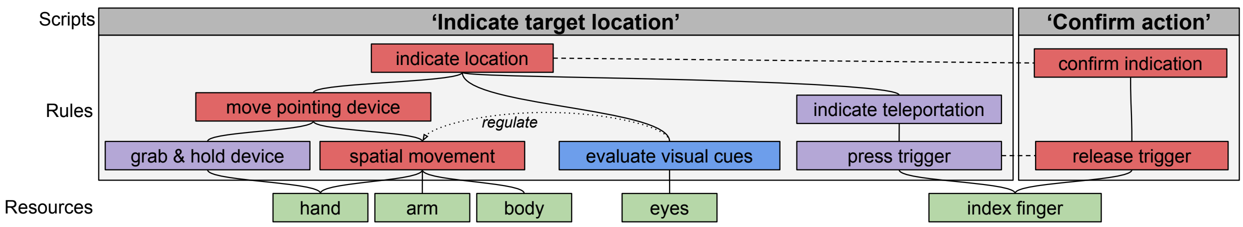

Figure 3: Schemata analysis for a generic teleportation IT. Active schemata are red (one-time) or violet (continuous), reception schemata blue. Resources are green.

application is dependent on the mapping between real-world input and SN re-interpretation. Schemata can easily be mapped when they behave symmetrically [MLP16] to a real-world counter part, or example, pointing with a ray in a VE and pointing with the index finger in the real-word. In contrast, more complex SN-ITs such as flying, do not necessarily have a real-world equivalent and mapping becomes more difficult.

The user input to control a SN-IT can be reduced to a recombination of real-world schemata that are re-interpreted to develop a new schema. This reduction can be further analyzed, for example, for teleportation in VEs. Research shows that teleportation allows an efficient and pleasant way of traveling in VEs [BRKD16, LLS18]. Even though teleportation is not possible in the real world and contradicts our real-world experience, this SN-IT can reliably be applied with only a short time of training. As a result, many VEs implement this IT to account for limited real space in a possibly unlimited virtual environment. To be able to use teleportation, the user first needs to retrieve the script form the context-dependent set of means-ends, that contains the information: 'in this context, teleportation can be used to change location'. In this example, this script contains a sequence of two sub-scripts that point to individual rules (see Figure 3). First, the user indicates the target location using a hand-held pointing device (e.g., a controller) and indicating the teleportation action (in this example, pressing a trigger button). Pressing trigger buttons is a generic action which can be mapped to different functions. The procedural actions (rules) needed to press a button are fairly simple which makes this scheme easily overlearnable. The indication can be supported by visual cues such as virtual rays that enhance the pointing direction and a virtual target at the selected location. By interpreting these visual cues, the spatial movement of involved parts of the body is continuously regulated, until the target location (which can also be a sub-location on the way to the final destination) is indicated. The second phase is the confirmation of teleportation, in this case, by releasing the trigger. After confirmation, the user input is evaluated by the computer system and the user position is shifted accordingly.

In this decomposition, the resource 'hand' is a shared resource between the parallel rules 'grab & hold device' and 'spatial movement' and 'index finger' is shared between the rules 'press trigger' and 'release trigger' and also the sequential scripts 'Indicate target location' and 'Confirm action'. Schemata share the external objects 'device' and 'trigger' and also the ideas 'location' and 'indication'. The schema 'spatial movement' is regulated by the schema 'evaluate visual cues'.

By replacing individual rules, variants of teleportation are generated. Instead of controller-based pointing, gaze tracking can be used to indicate location. Instead of using the trigger button, other generic inputs may be used to indicate teleportation. In all these cases, the user needs to have a 'tacit knowledge' [Joh88] on how the input works, as it is not possible to just retrieve a script from real-world interaction and apply it in the VE.

6 Discussion

The SBIC currently focuses on the basic process of chossing or building an action which is based on an initial intention. The literature on action theory and regulation is extensive and additional aspects can be integrated in the model in the future. In cognitive research, brain structures have been identified that are responsible for distinct processes in the ACT-R model, for example the thalamus as control for execution of actions [RTO19]. Due to the similarity between the SBIC and ACT-R, it could be possible to assign brain structures to distinct steps in the schemata model in the same way. The SBIC still provides a view from a different perspective on the design of SN interactions. It provides additional terms and concepts to describe different aspects of SN-interaction. For example, an error that originates in a selection of an inadequate schema to reach a goal may be called a 'goal-intention conflict'. Disassembling an IT in underlying schemata allows two main applications: First, ideation and interaction design. Individual schemata can be treated as building blocks for interaction and exchanging them with similar rules yields a new variant for this technique. Second, a structured mitigation of potential errors. Especially SN-interaction is error-prone as real-world interactions are not replicated (scripts from R do not necessarily apply), but are re-mapped, modified or recombined to allow novel ITs. Re-mapped generic schemata benefits from utilizing rules from the overlearned N-set, as executing these rules is already internalized. In a similar way, utilizing well-known cultural goods (that lie in the set of R), such a stories, superheroes or magic, or easy-to-grasp metaphors as design guideline may support developing cognitive schemata (the internal representation) of how the interaction works. While overwriting the mapping within a schema allows a generic use of schemata and different variants of an IT, it can also be problematic. Exchanging the function of two buttons after overlearning the interaction may reduce the usability drastically. For different use cases, the level of granularity may vary and good practices of applying this model needs to be developed in the future.

7 Conclusion and Future Work

While the schemata interaction cycle as model does not account for the whole, partially fuzzy, decision process in humans, it still provides a good foundation for analyzing and designing SN-ITs. In the future, the schemata interaction cycle will be expanded by integrating more research and perspectives on human actions to provide a holistic view on SN interaction, and human-computer interaction in general.

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