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An Interactive Space as a Creature:

Mechanisms of Agency Attribution and Autotelic Experience

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ABSTRACT

Interacting with an animal is a highly immersing and satisfactory experience. How can interaction with an artifact can be imbued with the quality of an interaction with a living being? The authors propose a theoretical relationship that puts the predictability of the human-artifact interaction at the center of the attribution of agency and experience of "flow." They empirically explored three modes of interaction that differed in the level of predictability of the interactive space's behavior. The results of the authors' study give support to the notion that there is a sweet spot of predictability in the reactions of the space that leads users to perceive the space as a creature. Flow factors discriminated between the different modes of interaction and showed the expected nonlinear relationship with the predictability of the interaction. The authors' results show that predictability is a key factor to induce an attribution of agency, and they hope that their study can contribute to a more systematic approach to designing satisfactory and rich interaction between humans and machines.

KEYWORDS

Agency, Alive, Animate, Flow, Intelligent Environment, Mixed-Reality, Predictability

INTRODUCTION

Interaction with animals can be regarded as the gold standard of a rich, engaging, and gratifying experience where the user is fully immersed and focused (Beetz, Uvnäs-Moberg, Julius, & Kotrschal, 2012). It would seem that interacting with things that are alive has a quality distinct from an interaction with inanimate matter. In order to purposefully build systems that are seen as alive, we need to understand what inferences humans are making. The distinction between what is alive and what is not is a fundamental perceptual category in humans (Wiggett, Pritchard, & Downing, 2009) that can be regarded as an "evolutionarily adapted domain-specific knowledge systems" (Caramazza & Shelton, 1998). The fundamental nature of this faculty is highlighted by the fact that already young infants seem capable of distinguishing animate from inanimate (Poulin-Dubois, Lepage, & Ferland, 1996; Schlottmann & Ray, 2010). We know factually that entities that are alive, entities that look alive, and entities that display agency belong to three distinct but intersecting sets (Figure 1a). The relevant question in our context is what subjective heuristics people use when making inferences based on observation of, and interaction with an entity. It is known that humans use a number of rules

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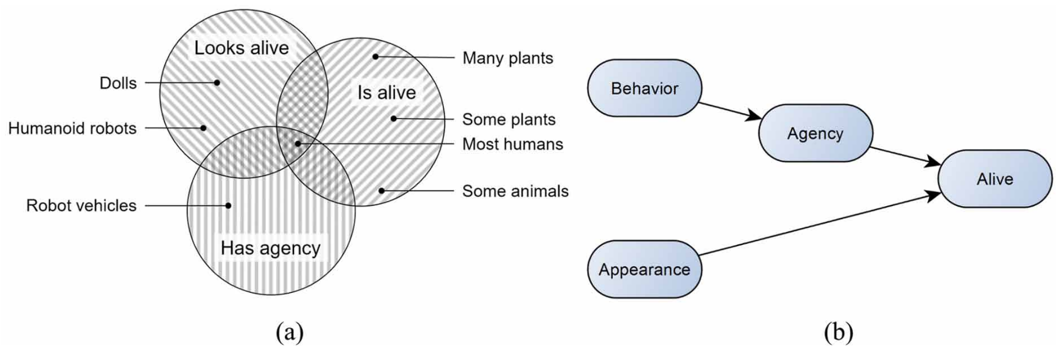
Figure 1. (a) Entities that are alive, entities that look alive, and entities that display agency belong to three distinct but intersecting sets. (b) Proposed heuristic used for determining if an entity is alive.



such as presence of face-like feature, and movement to determine what is animate (Jipson & Gelman, 2007). We hypothesize that the main factors for the attribution of animacy are the appearance and the (assumed) agency of the entity. Agency, in turn, is inferred from the observed behavior (Figure 1b).

In other words, we are assuming that the factors of attribution of animacy can be divided into static (appearance) and dynamic (behavior). The notion that behavior is a factor that is distinct from appearance comes e.g. from studies of the perception of animacy in abstract shapes moving in biologically inspired ways (Scholl & Tremoulet, 2000).

Though the mechanism of animacy attribution will not be entirely trivial, we assume that the factors "agency" and "appearance" will, by and large, contribute in an additive fashion to an attribution of animacy. Interesting scenarios will arise when there is a disparity between the two factors: We assume that a low level of agency combined with an appearance that strongly suggests animacy, leads to the "uncanny valley" effect (Mori, 1970). In the present study, we investigate the inverse case: The combination of high agency with an appearance that is not lifelike. Specifically, we are investigating factors of the interactive behavior that lead to an attribution of agency. We are interested in identifying those characteristics of interaction that lead to an attribution of agency, and how this is related to specific kinds of user experience.

Most studies investigating factors of agency use a passive paradigm where participants observe pre-recorded stimuli (e.g. Schlottmann & Ray, 2010). In our study, we investigate attribution of agency through a real-time interaction with an artifact. To bypass the influence of appearance factors we exploit an artifact that is explicitly non-anthropomorphic: An interactive mixed reality space. The viability of this approach is grounded in earlier work developed in a similar space where we were able to show that humans do attribute the property of entity to the interactive space "Ada" (Eng, Douglas, & Verschure, 2005; Eng, Mintz, & Verschure, 2005). In the present study, we use a system that is a further step beyond Ada called eXperience Induction Machine (Bernardet et al., 2011).

Dynamic Factors of Agency Attribution

In the present study, we focus on the dynamic factors that contribute to an attribution of agency, namely the temporal and probabilistic predictability of behavior. Our first hypothesis is that the level of predictability of the behavior of an object leads to the attribution of agency. Support for this notion comes from research on biological motion, that shows that one of the characteristics of biological motion is to be unpredictable (e.g. Mandler, 1992). To test this hypothesis, we designed and tested three modes of interactions. In these interactions, the internal logical behavior was the same but we introduced different factors of uncertainty and probability to increase the complexity of the interaction. A highly predictable interaction with the space means that it is always responding in the same way to the user's behavior. A medium predictable interaction means that the space not always will react in the same way to the user's behavior. And finally, an interaction of low predictability interaction with the space means that the space will never react in the same way to the user's behavior.

We foresee that there is a "sweet spot" of predictability in the reactions of the space that leads users to attribute agency to the entity they are interacting with (Figure 2). If the user easily understands the logic underlying the interaction he/she will leave the space with the sensation that all was automatic and the capacity of the space to interact with her/him was limited. Conversely, if the interaction is not automatic and never reacts in the same way, the user leaves the space with the perception of a random interaction.

Predictability and the Sensation "Flow" in User Experience

We have initially described interaction with animate things as being especially engaging and gratifying. The core factor of flow, and of particular interest here, is the equilibrium between challenge and skills (Figure 3a). We hypothesize that this factor of flow is strongly related to predictability; if the

Figure 2. Assumed relationship between the level of subjective predictability of the behavior of an object, and the attribution of agency to the same

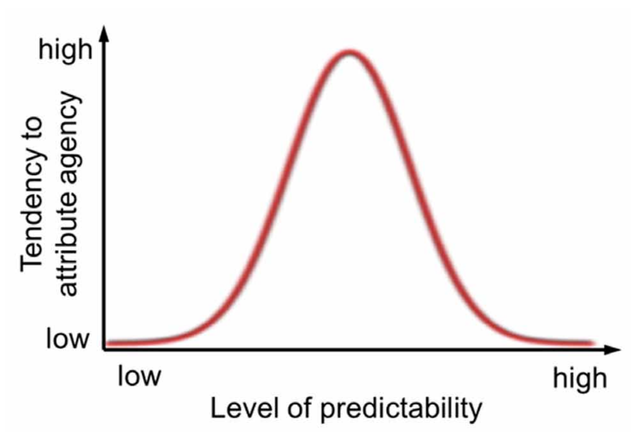
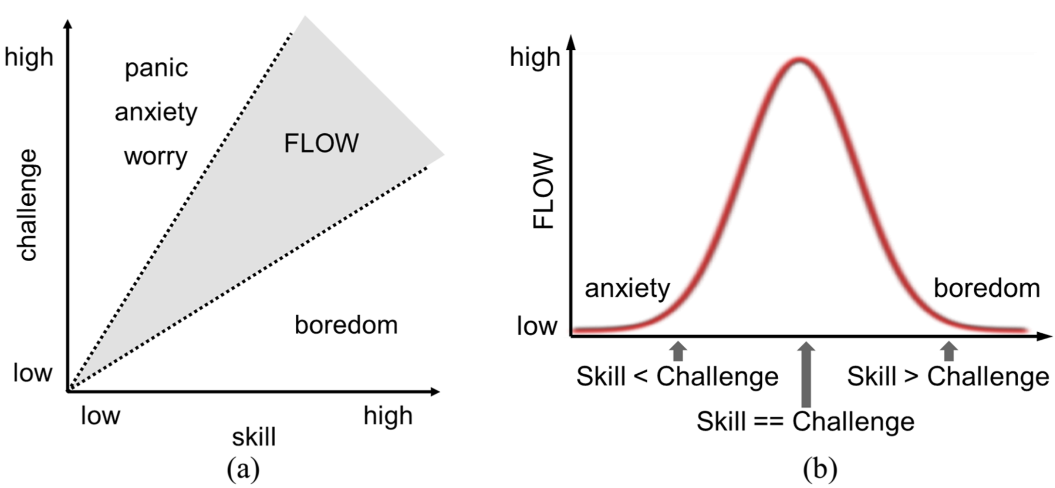


Figure 3. (a) Classical representation of "Flow" depending on Challenge – Skill balance (adapted from Csikszentmihalyi, 1991). (b) Experienced flow as a function of the skill to challenge ratio.



challenge is smaller than the skills, the user is able to easily predict the behavior of the system he/she is interacting with. Conversely, we assume that a challenge bigger than the skills will leave the user confused, as he/she is unable to predict the system's behavior. This notion is supported by the finding that for web users, the flow experiences is linked to discovery-finding, learning or observing something for the first time (Pace, 2004). Analyzing the concept of flow, we come to the conclusion that flow and attribution of agency share the core aspect of the predictability of the interaction. This link between these two concepts can explain why interaction with living things is able to induce a sensation of flow. Based on the above said, we formulate our second hypothesis: Flow and attribution of agency are related in that a subset of the flow dimensions overlaps with the attribution of agency, specifically the factors that relate to predictability. To test this hypothesis, we administered a flow questionnaire (Flow Sate Scale-2, Jackson & Eklund, 2004) after the participants interacted with the mixed-reality space.

Related Work

Over the past decades a number of mixed-reality and interactive spaces such as the Intelligent Room project at MIT (Brooks, 1997) have been developed (Bernardet & Verschure, 2009). One of the most sophisticated and largest multi-user systems was "Ada: The Intelligent Space," shown at the Swiss national exhibition Expo.02 (K. Eng et al., 2003). The space was conceptualized as an "inside out" robot, able to learn from experience, react in a goal- oriented and situationally dependent way. Uniquely, 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 (Eng et al., 2005; Eng et al., 2003). To design the technological artifacts as affording animal like interactions was a deliberate choice: As (Dautenhahn, 2007) points out, interactions with humans or other social animals is unique in the amount of emotional support, friendship, love and companionship we gain from it. Correspondingly, a number of studies have directly applied paradigms from human-animal interaction to artifacts for human-robot interaction (François, Powell, & Dautenhahn, 2009; Singh & Young, 2012; Wada & Shibata, 2007). As an entity imbued with autonomy, social ability, reactivity, and pro-activity embodied in a mixed reality environment, the XIM system presented here can be classified a "Mixed Reality Agent" (Holz et al., 2011; Wooldridge & Jennings, 1995). The subjective sense of presence – "the suspension of disbelief that they are in a world other than where their real bodies are located" (Slater & Usoh, 1993) v – is a highly relevant concept for the qualification of experience not only in virtual but also in mixed-reality. However, as pointed out by (Wagner et al., 2009), applied to mixed-reality, a more facetted view of the subjective experience beyond the notion of immersion is required. We deem multi-dimensional approaches to presence as proposed by Slater (2009) on the one hand, and Ijsselsteijn & Riva (2003) on the other hand to be the most promising for the application to mixed-reality. Slater (2009) distinguishes between the dimensions of place illusion (PI) – the feeling of being there – and plausibility illusion (Psi) -- "the illusion that the scenario being depicted is actually occurring." Particularly, plausibility illusion, that "is determined by the extent to which the system can produce events that directly relate to the participant, the overall credibility of the scenario being depicted in comparison with expectations" Slater (2009) fits well with the characteristics of the environment described here. Complementary to Slater's view, Ijsselsteijn & Riva (2003) are proposing a decomposition of presence into physical presence and social presence, "the feeling of being together with another person." The latter dimension of social presence (Bulu, 2012) seems especially well suited for mixed reality environments.

Next to presence, "Flow" is one of the core concepts that has been successfully applied to specify the quality of experience. Flow is described as a state where attention, motivation, and the situation meet, resulting in a kind of "productive harmony", and is typically found in autotelic activities, i.e. activities where the motivation comes from the individual him/herself instead of from an external source (Csikszentmihalyi, 1991). Such activities are characterized by intrinsic pleasures of creative action and are rewarding in and of themselves, regardless of any goals or outcomes. A number of everyday activities can induce a sensation of flow including reading, writing, doing sports and making art or music (Pilke, 2004). The concept of Flow is widely used in the investigation of technology-based environments (Ghani & Deshpande, 1994; Hoffman & Novak, 2009; Voiskounsky, 2007). Example include studies on e-learning (Tuunanen & Govindji, 2016), interactive art (Gilroy, Cavazza, & Benayoun, 2009), online virtual communities (Faiola, Newlon, Pfaff, & Smyslova, 2013), or tabletop gaming (Chen, Lin, Haller, Leitner, & Duh, 2009). Factors that contribute to the experience of flow include: Balance between skills level and challenge, absorption in activity, clear goals, unambiguous and direct feedback, concentrating and focusing on the task at hand, sense of control over the performance or activity, loss of the feeling of self-consciousness, distorted sense of time, and autotelic experience (Jackson & Eklund, 2004). Note that not all of these dimensions have to be experienced to reach a flow state and depending on the activity performed the magnitude of the experience along these dimensions vary.

The research space of our work is best characterized by a bi-directional relationship between the fields of human-computer interaction and psychology: We use methods and technology from computer science to elucidate psychological topics, and, conversely, use psychology to improve interaction with artifacts (Bernardet & Verschure, 2009).

METHODS

Subsequently, we will firstly describe in more detail the physical structure of the mixed-reality space eXperience Induction Machine, and the control logic guiding the interaction. Secondly, we are describing the experimental protocol and the measurement made in the study.

The Experience Induction Machine (XIM)

The experiments in this study were conducted using the mixed-reality system eXperience Induction Machine (XIM). The infrastructure of XIM comprises a rigid structure that covers a surface are of 550x 550cm, and a large set of sensors and effectors (Figure 4). The main system control of XIM is implemented using the large-scale neural system simulator “iqr” (Bernardet & Verschure, 2010). This neuromorphic simulation environment runs on the Linux platform and controls all sensors and effectors in real-time.

The Control System

To have parametric control over the predictability of the interaction, we implemented a feedback control system comprising a controller, control variable, and controlled variable. The role of the controller is to minimize the difference between the controlled variable (actual value) and the set point (desired value). To do this, the controller changes the value of the control variable that sets the value of the actuator.

In our system, the controlled variable is the participant’s position in the space. The actual position of the participant is provided by the multi-modal tracking system (MMT) that tracks the users by integrating information from the pressure sensors in the floor tiles, and the overhead infrared camera (Mathews et al., 2007). The set point is a given spatial location within XIM, and cannot be directly perceived by the user. Additionally, the set point changes over the course of the experiment. The controller minimized the error, i.e. the difference between the actual position of the participant in the space and the desired location, by controlling the actuators (Figure 5). As actuators, the system uses the sound system and the lights in the floor tiles. We use two types of sonification: Firstly, a heartbeat sound, and secondly a synthetic random melody that is generated with a “Pure Data” (Pd) (Puckette, 1996) patch using bifurcation of harmonics in a tree. Both sound effects are played continuously at a tempo and volume that are a linear function of the error: The larger a participant’s distance to the set point, the lower the volume, and tempo. The sounds were selected according to their assumed capacity to communicate a constant signal during the experiment. By default, the floor does not

Figure 4. Schematic view of the eXperience Induction Machine. The space is equipped with a number of sensors (1 ceiling-mounted infrared camera, four steerable color cameras, microphones), and effectors (8 steerable theater lights, 8 surround speakers, 8 video projectors). The floor comprises 72 hexagonal luminous tiles, each of which incorporates three neon tubes (red, green, blue), and three pressure sensors (Bernardet & Verschure, 2009)

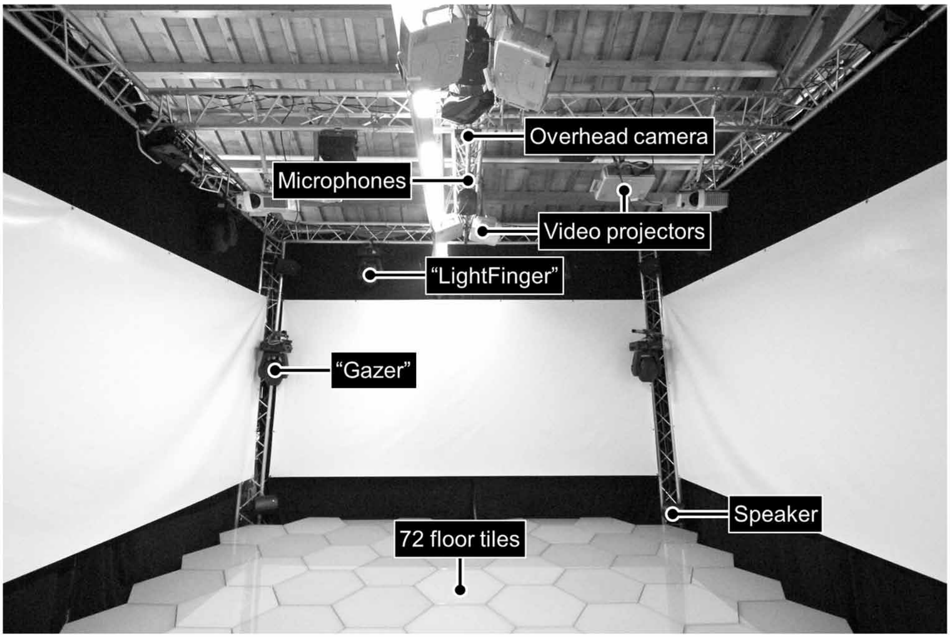
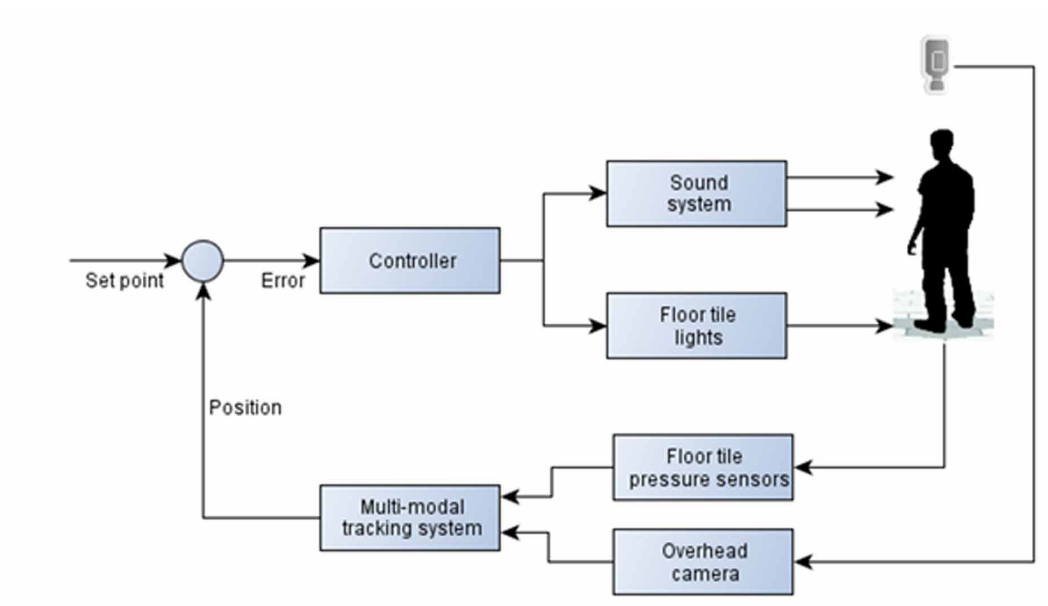


Figure 5. Feedback loop control of the interactions. The actuators of the system are the lights in the floor tiles, and the sound system. The participants in the room are tracked with the Multimodal Tracking System (MMT) that combines infrared tracking information from the overhead video camera with the tactile information from the floor (Mathews, Bermudez i Badia, & Verschure, 2007). While the controller is implemented using the large-scale neural system simulator "iqr" (Bernardet & Verschure, 2010), the sound effects are created with the Open Source graphical programming environment "Pure Data" (Pd) (Puckette, 1996). The communication between iqr and Pd is implemented using the Open Sound Control protocol (OSC)



indicate to a participant the location of the set point, but rather his/her current position by means of a lit floor tile that corresponds to a participant's position in space.

Once a participant reaches the hidden set point he/she receives a success feedback where all floor tiles blink for a brief moment, and hereafter the system defines a new set point location in the space. The position of the new set point and the success feedback were the two parameters manipulated to achieve different levels of predictability (see below). Overall the interaction paradigm is similar to the "Hunt the Thimble" game, with the main difference being that the participants were not given any prior information about the game logic.

Interactions Types

We designed three distinct modes of interaction that differed in their level of predictability (Table 1). In the case of the low-predictability interaction (Group A) two hidden set points are chosen randomly. As a second factor of "unpredictability", we define the probability with which the space displays the success feedback, and selects a new set point. If a participant reaches the hidden point, a new position is only generated with a probability of 50%. If the new set point is not defined, it will remain at the same position and sound effects do not change. The rationale behind this interaction type is that participants will not easily assess the internal logic of the interaction. For the mid-predictability interaction (Group B), as in the prior case, the position of the set point is randomly selected. The method to increase predictability, in this case, is to always give success feedback. In the high-predictability interaction (Group C) the two hidden set points are fixed to be always located at opposite corners of the space, hence rendering the interaction predictable, and of low complexity.

Experimental Procedure and Sample

Before the experiments began, participants were asked to give consent to have his/her data recorded during the experiments and were informed that they could leave the experiment at any moment in time without giving an explanation. Participants were not rewarded for participating in the experiment. At the start of the actual experiment, participants were asked to enter XIM, and explore the space, trying to understand what was happening in the space. Participants were told that they could stay in the space as long as they wished. To not influence the participants' perception of the room, no specific information about the space was given prior to the experiment.

We used an independent samples design to test the three modes of interaction. Each experimental condition was tested with 14 participants, yielding a total of 42 participants (22 males and 20 females). Participants were aged between 20 and 51 years (M = 28.071, SD = 7.103)

Data Collection and Measurements

To measure how participants perceived the space, a questionnaire comprising 14 five point Likert scale items was administered. Two questions directly assessed how participants perceived the autonomy and the animacy of the space ("How autonomous was the Space?" and "I felt that the space is a kind of creature"). Four questions were geared at how the space reacted to the user either by changing the floor lights, or the sound effects, volume, or tempo. A third set of four questions

Table 1. Summary of the three modes of interaction

Interaction type	Set point	Probability
low-predictability interaction (Group A)	Random position	50%
mid-predictability interaction (Group B)	Random position	100%
high-predictability interaction (Group C)	Fixed position	100%

assessed the perception of human control of the effectors of the room, e.g. "I felt that somebody was controlling the lights on the floor." We assume that these questions indirectly address the level of agency that participants attribute to space. One question asked participants to estimate the duration of their interaction with the space, and one open-ended question assessed what participants thought was happening in the during the experiment.

The Flow State Scale-2 (FSS-2) test was used to quantify the flow experience during the experiment (Jackson & Eklund, 2004). To focus participants on the activity they just completed, FSS uses a lead-in statement "During the event…" for each item. The rating scale for the FSS-2 is a five point Likert Scale and comprises a total of 32 items that measure 8 dimensions of Flow. We omitted the third Flow dimension ("Clear Goals") as we considered is not relevant in the context of our investigation.

In addition to the questionnaire and the flow scale, we recorded the spatial behavior of participants during the experiment (sampling frequency = 25Hz).

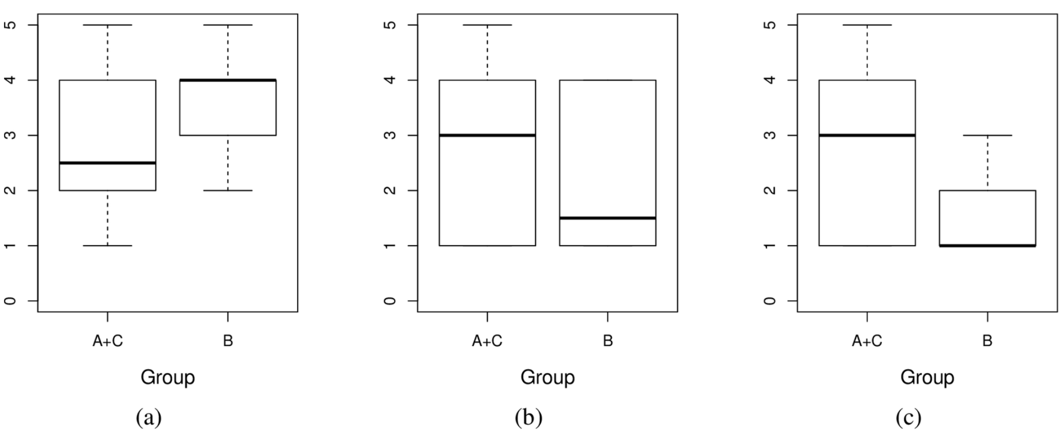
RESULTS

We analyzed the data using the free software environment R (R Development Core Team, 2011). A Kolmogorov-Smirnov test of the questionnaire data showed that it did not fulfill the normality criteria. Hence, to compare the three groups a Kruskal-Wallis test and posthoc Mann-Whitney U test with Bonferroni correction was used. Additionally, we combined groups A (low-predictability interaction) and C (high-predictability interaction) and compared this group to group B (mid-predictability interaction) using a Mann-Whitney U test. The rationale behind combining the groups was to corroborate our assumption that the medium level of predictability represents the "sweet spot" interaction, distinct from the extreme cases.

Questionnaire Data

For the animacy question "I felt that the space is a kind of creature" the comparison between combined groups (Figure 6a) was marginally significant (Mann-Whitney's $W = 130$, $Z = -1.481$, $p = 0.069$), while the Kruskal-Wallis test comparing the results of the three groups ($(2) = 4.539$, $p = 0.103$, was not significant. When combining groups A and C, we found a significant difference for the human agency item "I felt that somebody was controlling the sound effects" (Mann-Whitney's $W = 267$, $Z = -1.679336$, $p = 0.046$, Figure 6c), but not for the item "I felt that somebody was controlling the

Figure 6. a) Boxplots for the animacy item "I felt that the space is a kind of creature." b) Boxplots for the human agency item "I felt that somebody was controlling the lights on the floor." c) Boxplots for the item "I felt that somebody was controlling the sound effects"



lights on the floor" (Mann-Whitney's W = 245, Z = -0.944, p = 0.172, Figure 6b). Comparing the three groups for the items "I felt that somebody was controlling the lights on the floor" and "I felt that somebody was controlling the sound effects" yielded no significant difference (Kruskal-Wallis (2) = 1.944, p = 0.378 and (2) = 4.086, p = 0.129 respectively), but what we can see for both items is a trend that follows an inverted Gaussian curve.

When asking the participants "How autonomous was the Space?" there was no significant difference between the groups (Kruskal-Wallis (2) = 1.559, p = 0.459), but a trend for group C to rate the space as the most autonomous. The trend seen in this item is somewhat unexpected because for the item "I felt that the space is a kind of creature" group C yielded the lowest score. In the score of participants from the three groups, there was no significant difference in how much they rated that the space reacted to their action by either producing lights on the floor (Kruskal-Wallis (2) = 0.273, p = 0.872) or sound effects (Kruskal-Wallis (2) = 4.969, p = 0.083). For both of these items we can see a ceiling effect, i.e. most participants rated close to the maximum score.

Relationship between Flow Factors and Questionnaire Items

In accordance with our predictions, we analyzed the relationship between the questionnaire items and the Flow factors. We found a significant correlation between the question "I felt that the space is a kind of creature" and the flow factor "Challenge-Skill Balance" (Spearman's $\rho = 0.35$, $p<0.05$, Figure 7a). Additionally, a significant negative correlation was found between the item "I felt that the space is a kind of creature" and the ratio of perceived duration to effective duration (Spearman's $\rho = -0.44$, $p<0.01$). This correlation means that the more participants felt that the space was a creature, the more they underestimated the duration of the interaction (Figure 7b).

Flow

A Kruskal-Wallis test revealed a marginally significant effect of Group on "Merging of Action and Awareness" ((2) = 4.788, p = 0.091, Figure 8a). A posthoc test using Mann-Whitney tests with Bonferroni correction showed that the difference was between group B and C (p = 0.089). Visual inspection of the plot shows a Gaussian, curvilinear relationship between the level of

predictability of the behavior and the "Merging of Action and Awareness" factor. When combining group A and C, we found a significant difference between the combined groups and group B (Mann-Whitney's W = 122.5, Z = -1.641, p = 0.050, Figure 8b). For the flow factor "Challenge-Skill Balance" we did not find a significant difference between the groups (Kruskal-Wallis (2) = 3.554, df = 2, p

Figure 7. a) Correlation between the questionnaire item "I felt that the space is a kind of creature" and the flow factor "Challenge-Skill Balance", b) Correlation between the item "I felt that the space is a kind of creature" and the ratio of perceived duration / effective duration

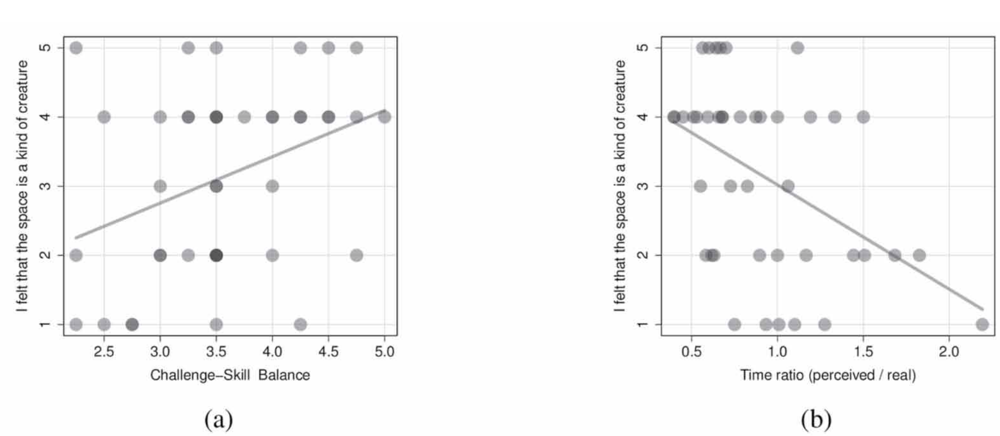
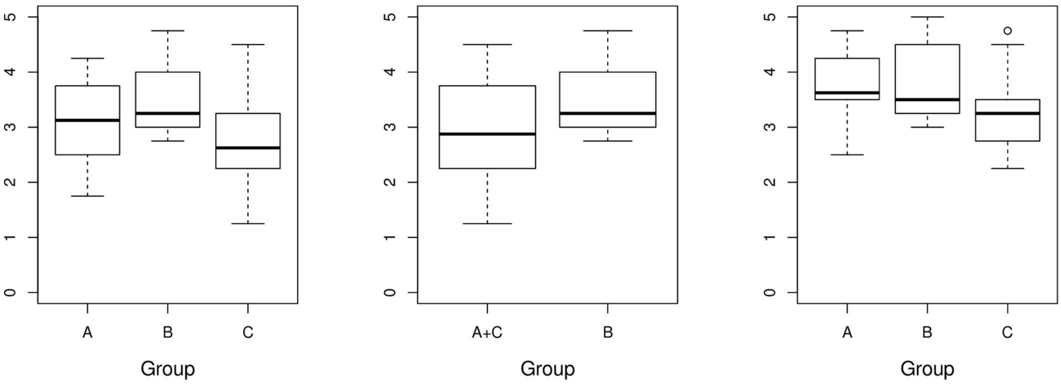


Figure 8. a), b) Boxplots for the flow item "Merging of Action and Awareness." c) Boxplot for the flow item "Challenge-Skill Balance"



(a) (b) (c)

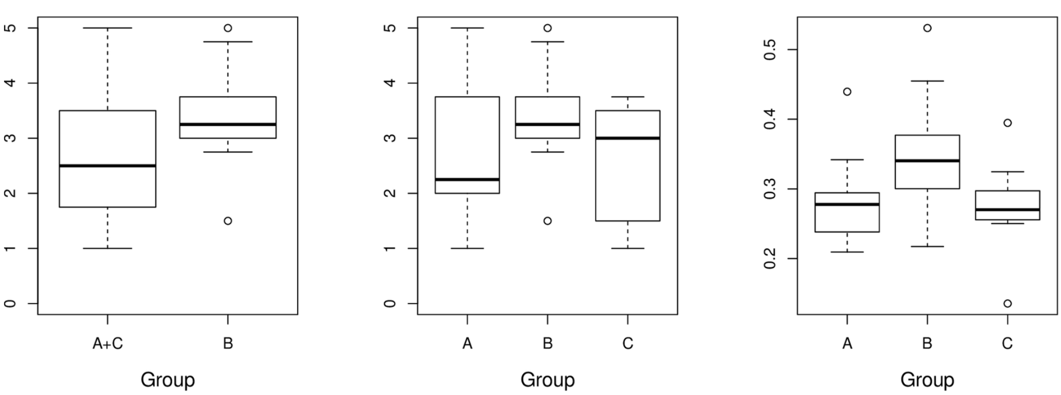
= 0.1691), though a trend can be seen that "Challenge-Skill Balance" decreases with the level of predictability of the interaction (Figure 8c). For the factor "Unambiguous Feedback" a Mann-Whitney's test revealed a significant difference between combined group A+C and group B (W = 116.5, Z = -1.822, p = 0.034, Figure 9a). The differences between the groups (Kruskal-Wallis (2) = 4.721, p = 0.094) was only marginally significant but shows a similar curvilinear relationship (Figure 9b).

Behavioral Data

During the experiment participants' location was recorded at a frequency of 25Hz (Mathews et al., 2007). Based on this data, we quantified the spatial behavior of the participants by calculating the average movement speed while interacting in XIM (Figure 9c). A Kruskal-Wallis test revealed a significant effect of Group on the mean speed ((2) = 9.9279, p = 0.007). A posthoc test using a Mann-Whitney's with Bonferroni correction showed the significant differences between Group A and B (p = 0.025) and between Group B and C (p = 0.019).

Additionally, we quantified the participant's perception of time by calculating the ratio between the estimated duration of the interaction and the effective time participant spent interacting: A value larger than 1.00 means the participants overestimated the duration of the interaction, while values

Figure 9. a), b) Boxplots for the flow item "Unambiguous Feedback." c) Boxplot of the mean speed of the participants during the experiment



(a) (b) (c)

smaller than 1.00 mean they underestimate the duration. A Kruskal-Wallis test showed no significant difference between the groups, but participants in all groups overestimated the time they spent in the experiment (estimated 467s vs measured 398s, mean ratio 1.28).

DISCUSSION

We could show that all three interaction modes tested in our study were designed such that participants could relate their own actions with reactions of the space, both with respect to the lights on the floor, and the sound effects. This is especially important for the low-predictability the condition, where participants should have more difficulty understanding the relationship, but not be left completely clueless.

Our first hypothesis was that the level of predictability of the behavior of the space is directly related to the attribution of agency. We found a significant, albeit not very strong, difference that discriminated between groups low-predictability and high-predictability on the one side, and group mid-predictability on the other: Participants from the mid-predictability interaction group significantly less had the impression that an instance external to the space was controlling the sound effects (Figure 6a). Moreover, we see for both cases, the external control of the lights on the floor and the sound effects, a Gaussian shaped trend, supporting our notion that the mid-predictability type of interaction is the "sweet spot" of predictability that leads users to attribute agency.

Secondly, we hypothesized that there exists a relationship between flow dimensions that relate to predictability and the attribution of agency. We found a significant difference for the two factors of "Unambiguous Feedback" and "Merging of Action and Awareness" when comparing combined groups low+ high predictability with group medium predictability (Figure 8a/b and Figure 9a/b), whereas the flow factor of "Challenge-Skill Balance" on its own was not discriminating between the groups (Figure 8c). Additionally, we found that the factor of "Challenge-Skill Balance" and the extent to which participants felt the space was a kind of creature correlated significantly. The behavior of the participants corroborates the relationship between the subjective immersion and the perceived animacy: Participants that thought that the space was "some kind of creature" moved faster, and were more likely to underestimate the time of the experiment.

CONCLUSION

Motivated by the observation that interaction with animals is a highly immersing and satisfactory experience the paper presented here pursued two aims: Firstly, to come to a better understanding of what heuristics humans use to determine if something is "alive", we want to identify what factors lead to an attribution of agency to an artifact. As the central characteristic of the interaction, we investigate the predictability of the behavior. Our second aim was to investigate the relationship between predictability of interaction and the subjective sense of "Flow."

We made two predictions: (1) there is a "sweet spot" of predictability in the reactions of the space that leads users to attribute agency, (2) flow factors that relate to predictability are correlated with the attribution of agency. Our experimental paradigm comprised of comparing three modes of interaction: Low-predictability, mid-predictability, and high-predictability. These modes were based on the same internal logical but varied in the level of predictability, that we modulated by varying the delay and the probability with which the system responded to actions of the user. The perception of the space and the flow experience were assessed with two separate questionnaires. Additionally, we recorded the spatial behavior of the participants and asked them to estimate the duration of the experiment.

We initially proposed that the main factors for the attribution of animacy to an entity are its appearance and perceived agency, which in turn is inferred from the observed behavior (Figure 1). The results of our study provide some support to the notion that predictability of behavior is related to the attribution of agency, and more specifically that there is a "sweet spot" of predictability in the reactions of the space that leads users to perceive the space as a kind of creature. Interestingly, we found no significant difference in how autonomous the participants felt the space was, but rather a trend that the group “high-predictability interaction” would find the space most autonomous. Combined with the absence of a correlation between these two items, this can be understood to mean that the concept of “creature” and “autonomy” are two distinct constructs. This is indeed in accordance with (Luck & D’Inverno, 1995) who define an agent as “an instantiation of an object together with an associated goal or set of goals”, distinct from an autonomous agent that additionally has a set of motivations associated with it.

Some flow factors such as unambiguous feedback and a merging of action and awareness were able to discriminate between the different modes of interaction and showed the expected nonlinear relationship with the predictability of the interaction: Both factors are rated highest in the mid-predictability type of interaction. We commenced the paper with the observation that interaction with living things is highly immersive and rewarding. Indeed, we found a direct relationship between the quality of the interaction as quantified by the flow concept and how much participants rated the space as animate.

We see the main limitation of the approach presented here at the level of the measurements: As pointed out by Slater (2004) in the context of measuring the subjective sense of presence, questionnaires can be highly problematic to measure experiential qualities. Ideally, questionnaires are replaced by objective physiological measures e.g. to quantify the subjective sense of presence by assessing the physiological response to “breaks in presence” (Rey, Parkhutik, Tembl, & Alcañiz, 2011). Indeed, several studies have been able to establish a link between physiological measures, and aspects of flow e.g. during piano playing (de Manzano, Theorell, Harmat, & Ullén, 2010) or playing computer games (Harmat et al., 2015).

We hope that our results can contribute to a more systematic approach to designing of satisfactory and rich interaction between humans and machines. For real-life human-computer applications our findings mean that interactions do not have to be complex, the artifact the user is interacting with does not have to have complex internal states to make the user attribute complex structures and be engaged in the interaction. In this way, we see our study as the application of the ideas behind Braitenberg’s (1986) vehicles applied to the HCI domain.

In future studies, we plan to further investigate the relationship between predictability and agency attribution. We will do this by, on the one hand, increasing the parameter search space, i.e. by testing the limits of what interactions users can still comprehend, and on the other hand by testing variations of how the two factors of delay and probability are implemented. Moving beyond the realm of interactive spaces, we plan to apply, and systematically investigate the concept of “unpredictability” in the interaction between biological and virtual humans.

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