Player Agency in Virtual Reality

- Comparison of Scripted and Meaningful interactions -

Thesis

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Abstract:

Agency is the abstract principle that an autonomous being is capable of acting by themselves. Player Agency is a concept from this, which states that a player perceives an increased capability to act themselves, if they are given meaningful actions. Agency is a fundamental craving of human nature, and by incorporating it into games, the satisfaction of the experience increases. Meaningful actions have previously seen designed as a branching point in a story. I propose another design, a meaningful interaction. I define a meaningful interaction as a self-contained integrated sequence, which the player can actively change the outcome of. To determine its effectiveness, I compare it to a scripted interaction, a predefined sequence, in which the player has no effect on the outcome. The study finds that a players perceived awareness of impact on the story is significantly higher in the meaningful condition, when compared to a scripted condition. This argues meaningful interaction as a valid method for increasing player agency.

Contents

Preface

I welcome you to my master thesis project in Medialogy! After 5 years, my studying journey seems to be approaching its end, and as a last effort, I delved into the field of agency, player agency, virtual reality and multiparty computation. Join me, as I explore what it means to be an agentic being, and how this is varies through different interaction modalities. Hopefully, by reading this, you will not only be slightly more interested in how interaction may improve your story, but become aware that this interaction can be a key method for making the player feel in control of the story. This study presents the one method for how a meaningful interaction can be implemented, and I urge you, the reader, to explore it further.

I would like to give a thanks to Martin Kraus, who gave invaluable input throughout the process, as well as the research group SECURE, who presented the topic Multiparty Computation, which is a concept I hope will become more prevalent in the future.

Aalborg University, May 27, 2019

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Chapter 1

Introduction

The movement and thought, the action and mind, are parts of what makes the human race stand out. They are not merely taking action for the sake of survival, instead, they are free of will and strong of conscious. We are autonomous, and possess the moral right to carry out desired decisions. The appeal of autonomy is not threaded lightly, instead it is exercises daily, it is of intrinsic value, not accepted but obligatory. This feeling of being aware and in control of one's own action is Agency. It is a fundamental craving of human nature, and we strive to feel it in every aspect.

> *"Agency, the satisfying power to take meaningful actions and see the results of our decisions and choices"*

Is how Murray envision agency[33], not as a need but as feel of power. This definition has inspired many scholars to pursue agency in game related contexts, which has given rise to the term Player Agency. There seem to be an undeniable connection between a persona in a game, and the person playing. This connection is an emotional link, which states the player will make choices based on a persona in a given media[26, 14, 10]. This is the theoretical aspect of Player Agency.

Another aspect, is the extent to which a player can choose to affect a story, their Perceived Player Agency. Through meaningful actions, such as impact the course of a story, the player starts to perceive themselves to be the agent of the story. One school of thought presents meaningful actions as branching points, where the user has to choose, in real time, how the story should progress[45, 44, 49]. These studies present interactive stories, in which the player is both exposed to linear choices (A choice which would not affect the story) and non-linear choices (A choice that affects the story, e.g. the story's ending will change). The player is then asked at every choice point, if they felt in control of their chosen decision. The idea is that perceived player agency increases when the player is given a non-linear choice.

In regards to perceived player agency, the studies present mostly inconclusive findings. At best, there seem to be a tendency for perceived player agency to occur at impactful branching points. I opt for a different vision of a meaningful action, not as a branching point,

but a self-contained sequence, in which the player can actively change the outcome. This is not a meaningful action, but a meaningful interaction between player and choice. Likewise, this is not an interactive story with branching, but a linear story with interactive elements. In theory, it would make for a linear story, with a perceived integrated effect, meaning that player agency will increase. As to explore this vision, the study presents two conditions, a meaningful condition and a scripted condition. In the meaningful condition, a player will have to complete a meaningful interaction to progress in a story. In the scripted condition they would have to complete a scripted interaction, defined as a predefined sequence with no integrated effect and only one outcome, to progress in a story.

Previous studies ran their experiment on a desktop PC. Virtual Reality (VR) offers a new media, in which one becomes the protagonist. Instead of watching the character on the screen, in VR, the role is assumed intrinsically. Introducing VR in an academic context, one quickly becomes aware of the term presence. Presence describes the unique feeling to VR of "being there". It is thought to occur when one is put in a virtual environment, and the brain starts to adopt the virtual reality as the current reality. It shares similarities to player agency, as they both deal with how we perceive the current media. If a strong presence is achieved, it might affect the player agency felt, and the connection can be explored. Therefore, the chosen media for the artifact was developed for VR.

The developed artifact was created in part with the research group SECURE (Secure Estimation and Control Using Recursion and Encryption). Part of their aim is to broaden the awareness of Multiparty Computation (MPC), a subcategory of cryptography. MPC's goal is to create methods, in which a set of agents can jointly compute a function over their inputs, while keeping those inputs private. Often these functions are complex, and difficult to understanding, making the concepts fall short of their potential. To solve this, the VR experience provides an explanation of self-developed MPC method, Additive Secret Sharing protocol (ASSP). The aim is that the person leaves the experience with enough knowledge to replicate ASSP.

Chapter 2

Exposition

Four main subjects are covered in this chapter, Agency, Player Agency, Virtual Reality and Multiparty Computation. Each section presents relevant studies for the area, which are used to inform both the experiment method and implementation details. Following these subjects, the survey instruments used to evaluate the experiment is presented.

2.1 Defining Agency

When one is in control of both action and thought, they are agentic of their mental state, i.e. they intentionally make things happen by their own action. This experience is referred to as agency. Throughout the day, agency is a pervasive coherent experience, that is a seemingly fluent thought, carrying out body movements, and inevitably affecting our surroundings. The outcomes of agency are not characteristics of agentic acts; they are consequences of them (e.g. [5]). Haggard et al. [21] describes agency as the successive states of sensorimotor control sharing a tight link, enabling us to predict action based on a desirable idea. One can quickly get a sense of agency, when they think of a task to complete. A task such as turning on the light, in most cases, one would already have designed their intention for pushing the button which, in turn, powers the light. Often forgotten is the step of coordinating one's body, performing the rather complex, yet natural, action of moving one's body for completing the action. What becomes apparent, is that when agency is coherent, it should unmindful action, merely there as a cogwheel for the greater mechanism to function.

However once this link is broken, the curtains falls as the illusion is broken. If the link is not there, we question whether we were the owner of said action. We start to ask ourselves "Did I turn on the light?".

From a cognitive viewpoint, research finds the mind understand agency as two co-here parts, the non-conceptual Feeling of Agency (FoA), and the higher-order Judgment of Agency (JoA) (e.g. [42]). FoA is the process required for an action, every step from forming a desirable idea, to fulfilling all the needs to complete it, whereas JoA is the retro-spective action of verifying the order of action, and if the expected outcome was achieved.

With this definition, at what point does the mind start to feel as if we are not agentic of action, in other words, the action is being performed by someone else, and not us? FoA relates to everything regarding action available and knowledge of so, whereas JoA relates to whether we achieved our desired idea. In most cases, FoA is straight forward, as it can easily be concluded whether or not a certain action can be fulfilled. One simply has to try it out. However, judgement proves slightly more interesting, as it becomes hard to determine at which point the judgement starts to weaken.

Research of agency dates back, already in 1983 Libet at al. [29] conducted an experiment on the conscious intention to act in relation to onset of cerebral activity. Their findings proposed the idea that actions can begin unconsciously, before any decision has been reached cerebrally.

Kühn et al. [25] conducted an experiment with the intention of making an objective analysis of agency. The participants would be trained to a certain pattern, in this case, clicking a button would make a specific sound occur after a 100ms, with a white box showing on the screen. A total of two buttons, each with their own tone of either 400hz or 800hz, were used. Then, after 300 training trials, participants Electroencephalography (EEG) were measured. During this, the buttons would at times, instead of playing its respective tone, play the incongruent tone, i.e. the tone expected for the other button. Further, the time between clicking the button and the sound played, would vary from 100-600ms. Each time performing these actions, they would rate their own agency on a scale from 1-100, where 1 being "me" and 100 being "Somebody else". The data showed an increasing loss of agency, as the time between clicking the button and the sound increased, with a significant difference between 100 and 600($p<0.001$)), as well as a steady difference between congruent and incongruent sounds at time sampled points ($p<0.05$).

Weiss et al. [48] conducted a similar experiment. Participants were seated, and asked to put their hand inside a box. Inside the box were a camera recording one's hand, which was then displayed on a screen in front of the user. The participants underwent 20 training trails, in which only intrinsic delay of less than 17ms was present. Afterwards they would be asked to repeat certain hand signs, following an animated figure on the screen, but recorded hand would be delayed by a varying degree of none, 100, 200 or 300ms. After each completion, they would be asked if the observed movement corresponded to their executed movement, as a yes-no response. When added delay to the observed movement, there was a significant loss of agency from none-300ms delay ($p<0.001$). Looking at the individual timesteps, the difference was significant between 0-100ms($p<0.001$), and 200-300ms($p<0.001$), yet insignificant between 100-200ms ($p = 0.765$).

The presented research gives an indication that through learned means we come to expect certain outcomes, and if those are not met, we lose agency. The assumption can be made that given the learnt means are respected, we feel agency. This assumption provides reason for the following sections, that we can gain agency for other objects. As long as we respect the given research, and give the players the chance to learn and understand the interactions, agency can be expected to occur. This gives reason that agency can occur in elements which

gives us the features to feel in control, meaning we understand the controls and have an expectation of the outcome.

2.2 Defining Player Agency

In games, agency of a player is a common design principle. The principles states that a players need to feel in control of their character, for a good experience (e.g. [9, 19]). Being in control is a fundamental part of human nature, and it is linked to improve your emotional wellbeing, improved performance and good health in your daily life (e.g. [6, 43]). The research surrounding player agency tends to define player agency based on Murray's definition of Agency; "the satisfying power to take meaningful actions and see the results of our decisions and choices"[33]. This defines agency, but at what point does the player enter the picture?

In a study by Waskul and Lust[47] they propose the *persona-player-person* boundaries, see figure 2.1. They argue that the individual playing an interactive narrative role-playing game is simultaneously; a) **a person**, with their own beliefs, desires, intentions etc., b) **a player**, who takes part of the conventions of gaming, and often socializes in a group who shares the same interest, and c) **a persona**, a narrative "self" that only exists in the interactive narrative's world. To further add onto this definition, Huizinga in Homo Ludens[22] describe the three roles, in a fantasy setting as: "Roles(Person), Play(Player), and Role-Playing(Persona): Reality, Imagination, and Fantasy". The player is the image this is formed in the imagination of a displayed persona, based on the traits said persona expresses. It is this imagination that the person uses to express themselves in their communities, not necessarily the objective truth, but the subjective thought, affected by their own person.

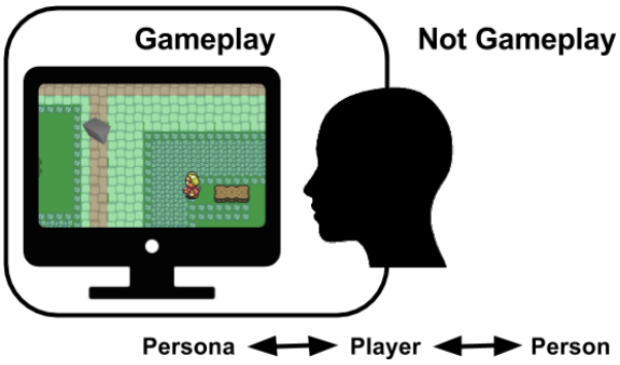

Figure 2.1: The persona-player-person boundaries by Waskul and Lust[47].

Thue et al. [45, 44] argues that player agency has two aspects, the personas autonomy, how related the person feel to that persona, and the players impact on the story, how the player perceive their ability to change elements in the story. These are respectively referred

to as Theoretical Agency and Perceived Agency, both being aspect that has been found to have an effect on player agency.

Theoretical Agency

Theoretical agency is the feeling of a narrative role in the story. Smith [34] conducted a study in which he compares the conceptual framework people use for interpreting (film) characters, to those they use to interpret other people. It was found that people ought to react emotionally to characters similar to how they react to real people. Lankoski [26] has further studied this idea and coined it as the Empathetic Engagement, a link that exists between the person and the persona. The Empathic Engagement is an emphatic understanding between the two, which in turn causes an additional interest in the narrative.

The Mimesis effect, as coined by Domínguez [14] in a recent study, defines the fact that when players were explicitly given a role, there is a significant relationship between the given role and the in-game actions. In their case, participants were given a role (Wizard, Warrior or Rouge), and were given a set of weapons, clothes etc. to choose between. They found a significant connection that by implicitly giving a player a predefined role, such as a rouge, a player was more likely to choose a dagger as their weapon, over a wand or a sword. The Mimesis effect states that people will role-play a given role, even if not instructed to, exhibiting a preference for actions consistent with their role.

Christensen et al. [10] conducted a study to gain insight, if player agency could be affected by what they propose as "Hover-Text". The hover text is an addition to the story, where when hovering the mouse courser over an option, a text will appear stating the inner monologue of the protagonist. They created a visual novel, which features purposeful-selective interactions[37]. Their results were gathered as a Likert scale, inquiring the participants engagement link following the experience. By giving the player a predefined role (In this case, by having the protagonist thought be present in the story), the player becomes more involved with the persona. On the other hand, they also report a tendency for players to feel that their choices were less about themselves. It is also worth reporting that a large deviation in the answers were present, arguing that the experience was greatly subjective. The presented findings show an implicit connection between the persona and the person.

Perceived Agency

Perceived Agency covers the perceivable effect a player has in a story. Day and Zhu [13] provides an overview of perceived agency, in both academia and industry. They conducted an exhaustive research of games fitting the scope (I.e. Telltales games[1], a company who is known for their narratives), and studies concerning themselves with identifying player agency traits. They arrive at the term Agency Informing Techniques (AIT), and its implications. An AIT is ways for which a game can be designed, such that the player feels agentic

[1] https://telltale.com/

of the story. They present six AIT's; Binary Choices, User Interface (UI) Cues, Choice Visualization, Choice Manipulation, Skill Checks, Visible Branching Points. Branching in a story means that that the story can change completely, depending on the choices made by the player. An example of a story with visible branching points can be seen in 2.2.

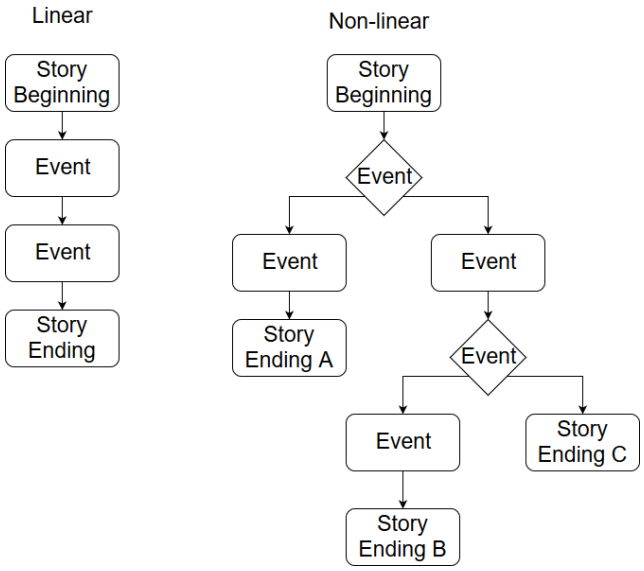

Figure 2.2: Example of linear and non-linear stories. The linear story only resolves linearly, whereas in the non-linear the story can take upon itself different endings depending on the players choices.

Binary choices are as simple as it gets; Decide between X action or Y action. The implication is that either decision can affect the story slightly down the road, i.e. saving a certain person (e.g. a bandit) could benefit you, or it could be an obstacle. **UI queues** are not choices, but instead UI elements which suggest the story has had a change, i.e. after failing to help a friend, a text bit will show "Your friend will remember that". **Choice visualization** is using objects in game to inform agency, an example would be adding particle effects to symbolize that the character is showing a certain emotion. These effects are more common in first person games, in which they are used to symbolize weakness, rage etc. **Choice manipulation** is giving the player the ability to change story elements, post the event happening. An example employed in Life is Strange[2], is giving the player the ability to rewind time, to reconsider their decisions. **Skill Checks** are used in games where players have certain skills, often times they can train these skill to become more powerful. These checks are often used to impose a restriction, i.e. the player might need to train their strength to lift a boulder, in order to progress in the story. Lastly, **visible branching points**, are points in the narratives in which the player is forced to go down a certain story paths, which affects the story drastically. Often these are the moments at which the story can take a completely different ending.

[2]https://lifeisstrange.square-enix-games.com/en-us

Thue et al. [45] initially proposed the idea that for player agency to occur one also needs to have a desire for the decision taken. They designed an experiment testing this idea, by created an adaptive story in which the player had a set of binary choices as well as visible branching points. In one condition, the player would play this interactive story, and report their agency on a Likert scale at any point they needed to make a choice. In the other condition, the player would not have any decisions, instead they could only follow the path of previous play through, eliminating the perceived agency. They would give their report their agency at the same points as the first conditions. Their reported difference in agency between adaptive vs. fixed was insignificant (p=0.251).

To understand the importance of high agency, Fendt et al. [49] conducted a study in which they created a short story with six decision points(Binary Choices), in which two were true branching points (Visible Branching Points). The results were gathered through a Likert scale, included question regarding the feel of agency (e.g. on a scale from 1-5, rate "I felt like I had control over the aspects of the story I wanted control over"). No decisive results were concluded from the test, but they found a tendency, that decision which can lead in a fatal direction, increases the players feel of agency.

The presented studies follow a similar approach, that to achieve player agency, a story needs to allow the player to take meaningful actions. The meaningful actions were implemented in the form of branching choices. There findings were generally inconclusive and it is unsure whether these methods were able to make a person feel player agency.

A currently unexplored field in player agency is the *doing* of the action. The presented stories all rely on the same means for modalities for progressing the story, namely through a button press. There seem to be a gap in the research, as to what importance the **interaction** to perform this action have for player agency.

Therefore, I propose a different approach for incorporating a meaningful action into a story. Based on Salen and Zimmerman [38] description of meaningful play, Meaningful interaction occurs when the relationship between action and outcomes are both discernible and integrated into a larger context of the system. Discernible means that the player is able to perceive the outcome of the action, and integrated refers to the fact that depending on how one complete the action, the outcome will change.

An opposite of a meaningful interaction would be a scripted action. A scripted action is a discernible action with no integrated outcome. It needs to be discernible, as otherwise the action would not be related to the story.

As to test this approach, a linear story will be designed, with two conditions. One condition aim for a high player agentic experience through a meaningful interaction, whereas the other aim for a low player agentic experience through a scripted interaction. The scripted interaction is a static experience, in which one can only progress the story through a predefined action. This would make it so that one has no influence on the story. The meaningful interaction integrated into the story, meaning that it can completed in various ways, with multiple outcomes.

2.3 Virtual Reality

Virtual Reality (VR) technology is made to make itself disappear and engulf us. It is supposed to be perceived as the current reality while using it (e.g. [32]). Current technology available for consumers typically consists of a head-mounted display and a set of controllers. Tracked controllers follow your hand movements, and allow for interaction with virtual objects in the environment. These means cover only a small part of our entire sensory system, but they have still been found to make for strong experiences. These strong experiences rely heavily on the *presence* felt in the system; a term meaning "the sense of being in an environment" [17] and particularly relevant for VR.

The research regarding presence has been going on since VR first came about, and Bailenson [4], a longtime researcher of its psychological aspects, describes VR as an unusually strong illusion, unlike any other media. He proposes that a VR experience should not be understood as a media experience, but as an actual experience. Yet, for this to be achieved, there is a need for the users to believe the reality they are in.

Another term, similar to presence – and often used interchangeably – is *immersion*. Oh et al. [35] provide a distinction between the two concepts, with presence as the psychological experiences afforded by mediated communication, and immersion as the technological qualities. Slater and Wilbur [40] describe a successful immersive medium as "an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant". It relies on several technological features such as audio and visual quality, frame rate, stereoscopy, and field of view [11]. Presence can be defined as a subset of three into categories focusing on subjective measures: telepresence (spatial presence), self-presence, and social presence (co-presence) [27].

Cummings[11] and Bailenson[4] provide a study on several significant immersive features. They mention sound quality and natural interaction as impactful factors for immersion. They also provide several other significant findings on the challenges involved, although some of them can, arguably, already be resolved with today's powerful hardware. [11]

Telepresence is "the extent to which one feels present in the mediated environment, rather than in the immediate physical environment" [41]. Wirth et al. [50] propose a model, which argues users need to develop a mental model of the space depicted by a media offering. This spatial mental model is regarded as a necessary, albeit not sufficient, precondition of spatial presence. Second, users may accept the spatial model as their own egocentric viewpoint. If they do, spatial presence is assumed to emerge. The assumption is that the more concise (consistent, error-free, evident) the spatial mental model, the stronger the spatial presence will be.

Self-presence refers to the extent users connect with their own body in VR – how closely one feels that the "virtual self is experienced as the actual self" [3]. In a mediated virtual environment, the synchronous connection between the user's physical and the avatar's virtual movements play a critical role in inducing self-presence [3, 15]. Waltemate [46] further adds that a personalized avatar significantly increases body ownership. Lastly, self-presence is

argued to heighten in an explorative environment which reacts to the user's inputs [27].

Social presence is the perceived "sense of being with another" [7]. Oh et al. [35] proffers that one of the unique features that influence social presence in virtual environments is the visual representation of the communication partner. In the same study, they identify that current evidence indicates that people feel higher levels of social presence when there is a visual representation available, and if that visual representation exhibits behavioral realism (e.g. blinks naturally, shifts positions, breathes etc.). Given the experiment will require a facilitator to help to guide the participants along, social presence can be improved by making the facilitator a virtual agent with a visually realistic model. This both ensures consistency in presentation of the experiment, and will heighten social presence.

2.4 Scripted vs. Meaningful interaction

The desktop PC has been around for a long time, and it has been accepted into most homes. This has been the most common media for interactive stories. On the other hand, VR is rather new and still unexplored by many. It means that what makes a scripted and what makes a meaningful interaction is not clear. As to define the difference, I explore two different story-based interactive VR application, based on the definitions given on scripted and meaningful interactions presented in 2.2.

TheBlu[3] is a VR application on steam. Through it, you get to explore the ocean and it discover some of the hidden creatures underneath the surface. In it, the user can affect schools of fish and alike by waving the controller towards them.

The Stanford Ocean Acidification Experience [4] is another VR application on steam. In it, you experience ocean acidification, a process by which the ocean becomes more acidic as it absorbs carbon dioxide (CO2) that has been emitted into the atmosphere. The experience aims for making the user aware of this, through an interactive experience. Examples include grabbing objects and hitting a sphere to continue to the next scene.

For the most part, the presented interactions are meaningful, as they give the user the opportunity to experience the VR at their own terms, with a visible effect of their interaction. The user decides themselves how to approach the interactions continue. On the other hand, an example of a scripted interaction is hitting the sphere in the Stanford Ocean Experience, to progress. There is only one way that the user can progress in the story, removing the integration into the story.

2.5 Multiparty Computation

Multiparty Computation (MPC) is a field of cryptography, which is used to describe protocols in which a set of agents who each have an input can jointly compute a function over their inputs (Such as finding the average), without sharing their individual input. This is

[3] https://store.steampowered.com/app/451520/theBlu/

[4] https://store.steampowered.com/app/409020/The_Stanford_Ocean_Acidification_Experience/

done through a function, that each agent executes simultaneously, which when used in combination becomes the MPC protocol. The general theory of MPC was established already in the late 80-ties, but albeit already back then proven to be a method argued to be provide high decentralized security, it have seen few practical applications[8]. This has however changed in reason years, as several studies have found uses for it[8, 2, 20, 30, 31], contributing in making MPC a technique available for the end-users, meaning that organizations has started to pick up interest in the concept.

Often these sort of research papers deal with complex matters, Lapets et al. [2] worked towards making an MPC structure useful for organizations to collect aggregated data to use for statistical analysis, Lindell and Pinkas [30] discusses MPC for privacy-preserving in data mining, and Liu et al[31] who developed a programming framework, to help broaden the technical applications of MPC. These studies explain the concept in great detail, but this is most likely also the cause that in a Bogetoft et al's[8] study, in which MPC was used as a secure method for computing the market clearing for beets, the results for the application was successful, but as a side note they notion that 80% of the users did not understand the concept.

There has been a wave of stronger security means ongoing for years. Consumers wish for more protection online, as seen in a recent study by Gallup[12], in which 1.019 Americans participated in. They found that 71% worry occasionally or frequently about their personal data gets hacked, and 67% worry of identity theft. Compared to a real-life threat, only 40% worry of their home being burglarized. People feel unsecure with the current means of protecting themselves online, and introducing concepts such as MPC could help solve this. But if this were to be the case, having security methods used, which 80% of their users may not understand, is simply not good enough. Following this gap, the story will focus on teaching MPC. Using VR is found to have a recalling accuracy increase of 8.8% [24] vs a desktop monitor, reasoning this as a good approach for teaching the concept. MPC is a rather complicated field of mathematics for an uninitiated. Instead of delving into the specifics of the concepts, the core idea of MPC could help the average person gain an interest for the field, or at least an understanding of the basic concept.

The idea I wish to present is that through MPC, three or more people can keep their input private, while still computing the total sum of them. I refer to this as the Additive Secret Sharing Protocol (ASSP). ASSP is based on the protocol presented by Shamir[39] in his article "How to Share a Secret".

The algorithm for ASSP is as follows; The i-th party is denoted as p_i with $1 <= i <= N$ and $N >= 3$. Each party has their own secet s_i and a vector of shares $H_i = (h_i, 1, ..., h_i, N)$. The shares have to fulfill the following conditions:

$$\textbf{1: } h_{i,j} \geq 1$$

$$\textbf{2: } s_i = \sum_{j=1}^{N} h_{i,j}$$

The shares are distributed as $D_i = (d_{i,1}...d_{i,N})$, where

$$d_{i,j} = h_{j,i}$$

p_i party will only be able to see D_i. The shares are combined as $c_i = (c_1...c_N)$, where

$$c_i = \sum_{j=1}^{N} d_{i,j}$$

Every c_i are shared with every p_i, which then can be added to show

$$\sum_{j=1}^{N} c_j = \sum_{i=1}^{N} p_i$$

which shows that the average sum of all inputs can be found without any party's secret being shared completely.

The ASSP does fall into the pitfall that people with your input would be able to know your secret is at least $(N-1) + d_{x,y}$, where d_{x_y} is the share they received from you.

2.6 Survey Instrument

To evaluate the meaningful and scripted interaction a survey instrument is needed. The study provided in section 2.2 all provide their own questionnaire. They all use questionnaires with Likert scale answers from 1-5 (1:low, 5:high), but use their own variety of questions. Fendt et al. [49] studies question can be seen in table 2.1, and Christen et al. [10] can be seen in table 2.2. Thue et al. [45] did not provide their questionnaire, but refer to be inspired by an interactive story questionnaire presented by Klimmt et al[23], see table 2.3. In Klimmt et al's survey [23], they provide an empirical evaluation, basing their questionnaire on a series of previous studies. They divide the study into three sections; A (Q. 1-5): Preconditions for meaningful user experiences; B (6-10): Common and frequent experiential qualities, and C (11-13) Experience measures adaptable to specific systems.

The questionnaire is meant to be a general tool for all means of interactive stories. Based on this, Klimmt et al's questionnaire is adopted and used in this study. The questionnaire was chosen to keep intact, to help others compare their results to the ones gathered from this study, if they wish to do so. A slight change is to add a bit more descriptive information to some of the questions, as previous experience taught me that non-native English speakers often do not understand lesser used English words, such as "Inquisitive".

The studies regarding VR, as presented in section 2.3, are by many considered state of the art for achieving a presence rich environment. Telepresence, Self-presence and Social Presence will be used to inform the design of the prototype to enriching presence. To evaluate presence, this study uses the cross-media presence questionnaire ITC-SOPI [28], which consists of 61 questions, which deal with four factors: *Sense of Physical Space*, *Engagement*,

I felt that the actions I took were meaningful within the context of the story.
I felt that my actions were important to the progression of the story
I was able to see the results of my actions.
I felt that the story would have been different if I had selected different choices.
I felt like I had control over aspects of the story that I wanted control over

Table 2.1: The survey used by Fendt et al. [49] to determine player agency.

When playing the game, I was able to see the result of my actions.
I felt that the story would have been different, had I made different choices
While playing the game, I could relate to how the player character was feeling
I did not get involved with the feelings of the main character in the game
When playing the game, it was difficult for me to view things from the player character's perspective
I made choices based on what I felt that the player character would do
I made choices based on what I felt I would do
I made choices based on what I felt would yield the best result
I felt, I was not part of the story, but rather someone off screen, guiding the player character in the right direction

Table 2.2: The survey used by Christensen et al. [10] to determine player agency.

I thought the system was easy to use
I expected the experience to be more engaging
I felt like I was part of the environment in the presentation
I could feel what the characters in the environment were going through
My inputs had a considerable impact on the events in the game.
During the experience I felt inquisitive (Interesting, exciting)
At some moments I was anxious to find out what would happen next
During the experience I felt competent enough to meet the demands of the situation
I found the experience inspiring
The experience was gratifying
At this particular moment I feel excited
At this particular moment I feel sad
During the experience I felt like I was in the main characters skin

Table 2.3: An empirical survey for interactive stories created by Klimmt et al [23].

Ecological Validity, and *Negative Effects*. If there is connection between presence and player agency, the result gathered for presence is expected to differ between the two conditions.

To evaluate MPC, a small questionnaire was developed. The questions were based on how the participant feel currently of their security, and if this experience has helped them feel more aware of it. The questions can be seen in table 2.4. All the questions were presented as a liker scale from 1-5, 1 being low and 5 being high. The first question will be asked at the start of the experiment, and the last three at the end of it.

Rate your encrypt knowledge! Pick a fitting value, for your awareness of encryption methods
Do you feel more aware of encryption methods?
Do you feel as if you could replicate the Additive Secret Method?
Do you feel in control of your own personal data online?

Table 2.4: The questionnaire to assess the participants in regards to online security, and ASSP.

Chapter 3

Artifact Design

This chapter covers all aspects related to designing the story and the artifact, and the iterative process. The meaningful and scripted interactions are designed, and a summary of the storyboard is provided.

3.1 Story, Narrative and Plot

The art of telling a story is a old act, with a rich history. The effect of a story is not lost, and instead books, movies, games, the tale told around a campfire, are all activities exercised regularly to this day. The definition of a story varies from scholar to scholar, but a general consensus, as described by Abbott [1], defines the following concepts; the Story, Plot, Narration and Characters. A story is a telling of several events, within a given time frame. The method of which these events are told, is its narration. The plot is the focus of the story, and is there to support it, so that it is not a series of one thing after another, but instead a series of coupled events connected by an underlying cause. The characters are entities whom are present in the story.

3.2 Story idea

The general concept for the story is:

" A story with interactive elements in Virtual Reality, with the goal of explaining the Additive Secret Sharing Protocol. It should have two conditions, meaningful (High player agency) and scripted (Low player agency). "

The description of the story, being a story with interactive elements, as opposed to interactive story, is due to the fact that an interactive story is most often associated with a branching story, which is not the case for this study.

3.3 Iterations

The script and design were a work in progress throughout development, and went through multiple iterations. This includes slight changes to the story, to complete removal of concepts. The more prominent of these are addressed here.

3.3.1 Settings

The first iteration was to have the entire story take place inside a train wagon. During this stage, the idea was to have a fully animated character guide you, using Motion Capture data for movement. The idea was in the end scrapped. A train wagon was deemed too small to have the entire experience taking place in there, and it lacked reason as to why this whole story would take place. Further, there's a variety of free motion capture available, but it would be a time-consuming job figuring out which would work for this specific task. This was changed to a science lab instead, which was the final setting.

3.3.2 Characters

Three characters was designed, one being a VR controller model, animated to seems alive, and two others being animated heads displayed on a screen, using motion capture. This should, in theory, have been a doable process using the technology on devices such as iPhone X to capture certain head movements and replicate them on a 3D model using blend shapes. However, I was unable to acquire the needed technology, and in the end, the idea was scrapped. Instead, in the final version, a video recording was used in place of the animated heads. The VR controller model was kept as planned. It would have been preferable to use 3D animated heads, to keep in line with the rest of the animated settings.

3.3.3 Removed concepts

When discussing security breached, there is a rich history of breaches, in 2018 alone, there were a total of 2.3 billion data records hacked, and 557 recorded breaches [18]. These facts could give the user an idea of why securing our data is a desirable approach, but it seemed groundless to be fact showing, without reason. In the end, it was not a necessity for the story nor to explain the concept, and ultimately cut from the final implementation.

Another idea, which was left out, was explaining what encryption is and means. Similar to aforementioned concept, explaining encryption is relevant for the MPC, but not a necessity. Therefor this was cut from the final implementation. It is worth noting that this concept was almost fully animated, before it was cut. Figure 3.1 shows how it could have looked.

3.3.4 Visualizing Additive Secret Sharing Protocol

ASSP is a longer process with several steps, which without proper visualization, becomes difficult to grasp. A text-example of the planned ASSP implementation is, 1; Generate a

Figure 3.1: The "Enigma" machine, showing a password entering it, and the encrypted version leaving it.

whole number for each agent (These are the secrets). 2; Fragment into an amount of whole number pieces equal to the number of agents in the network, which would add up to the secret (These are the shares). 3; Share one of the shares with the other agents. 4; Add your own share, and the received shares. 5; Duplicate the newly achieved number equal to the number of members in the network. 6; Share a duplicate to each member. 7; Add the numbers. This value is the average of all inputs in the network.

This gave reason for a visual implementation of the algorithm. The secret was written as numbers. A linear interpolation was applied when sharing the shares, to make it more obvious that the numbers are being sent to the other parties. To visualize fragmentation each secret share was given a bar, representing its value. When the secret was fragmented, one could see that it was a part of the secret. The final design can be seen in figure 3.2. The colors for each figure were randomly chosen. The numbers were randomly chosen to be between 4-8, with no duplicates. These decisions were made, to make each number more distinguishable from each other. The implementation was made such that it could scale to any number of parties, but did not end up becoming relevant for the final artifact.

Initially, the user would watch this visualization of ASSP, similar to a movie. It was found through internal testing that it was hard to follow and comprehend the concept, if one was not given due time to collect the information given. It was changed, such that the user had to press a button to continue to the next step in the protocol, making them set the tempo themselves.

3.3.5 Questionnaire in VR

As stated in section 2.5, there is a wish to ask a series of questions related to security and ASSP. Given they are directly related to the experience, it decided that the questions will be asked while inside VR experience. The questionnaire consists of, in total, of four questions, each a Likert scale of 1-5. One question in the start of the VR experience, and the last three in the end. Initially it was implemented such that one would need to grab an object and put it on one of five platforms, each platform representing one of the Likert values, to give their

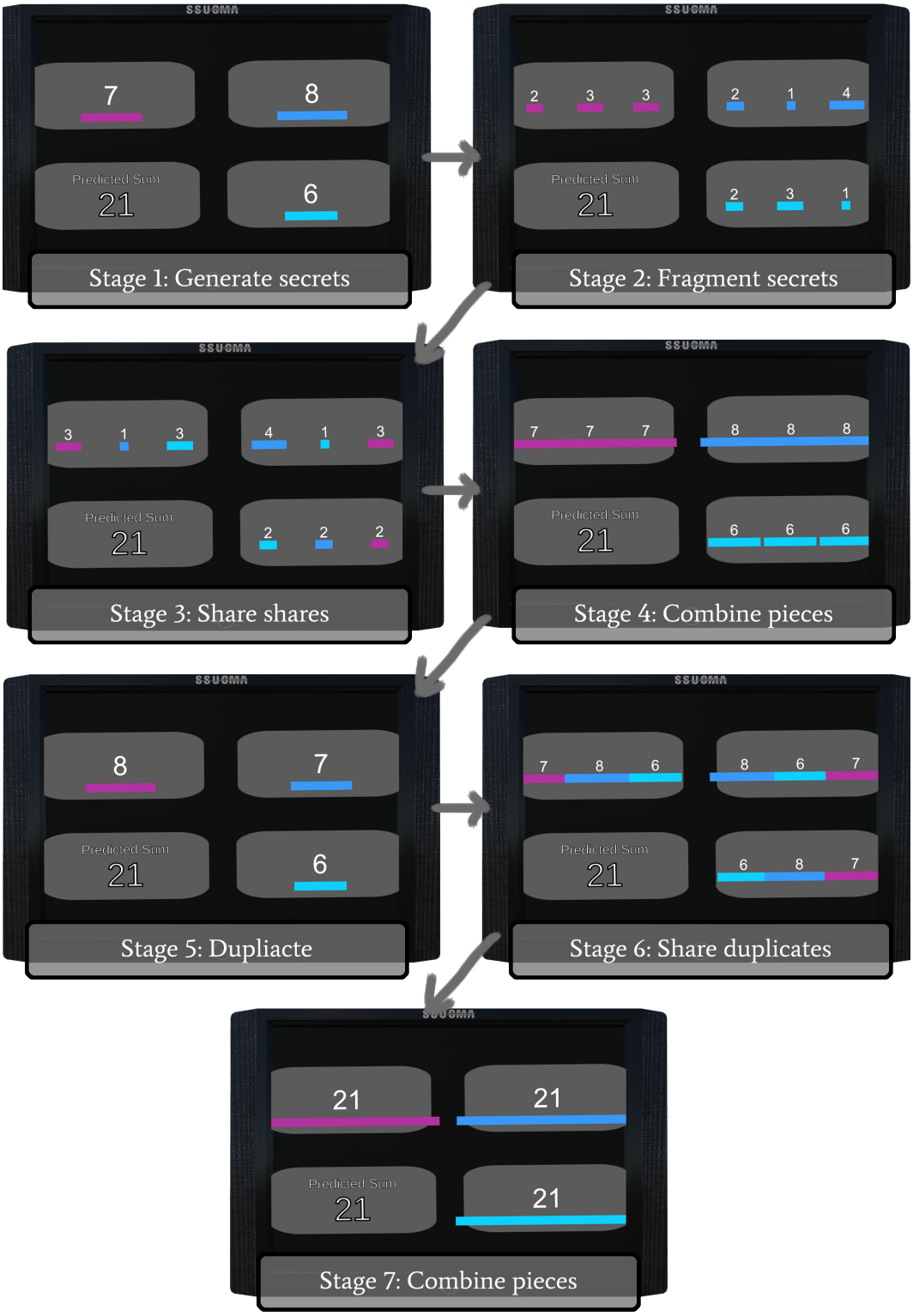

Figure 3.2: The visual version of the Additive Secret Sharing Protocol.

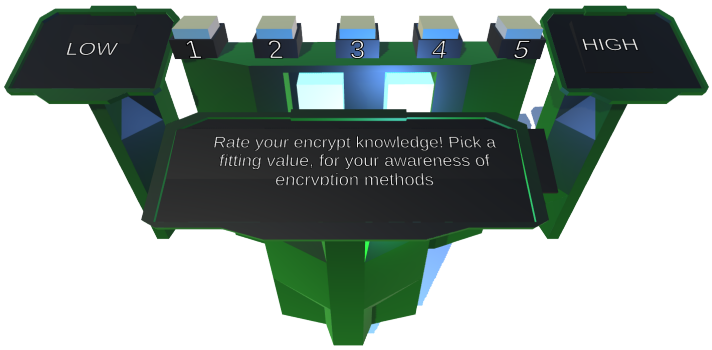

Figure 3.3: he likert scale for which the participants can rate themselves in VR.

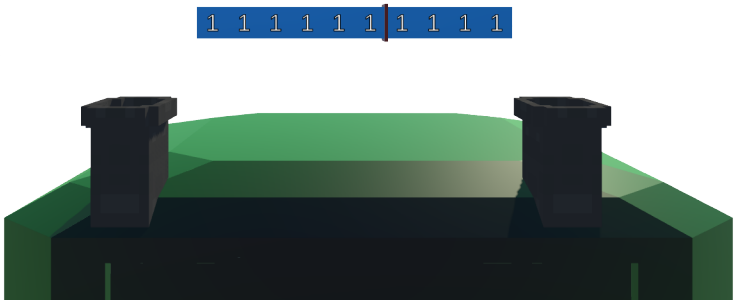

Figure 3.4: The predefined number, in which the user has to select the point at which to split it into the fragments.

answer. After some internal testing this was discovered to be a bit of a convoluted method of achieving what could be done through a button press, and it was changed to a series of five buttons instead. The final design can be seen in figure 3.3.

3.3.6 Meaningful Interaction

It was decided early on, that the meaningful interaction should come by taking an active part of the ASSP process. The player would first be shown the visual example of ASSP, as explained in section 3.3.4, which would be followed by them actively performing parts of ASSP. Initially, it was designed such that the player would have to write their own secret number, to add the protocol. But it was changed later in the project, as it was found difficult to implement in a meaningful way, into a story. Instead, the player would be given a predefined number, and select the ranges of the shares. Further, they would also be asked to give the shares to the other parties, as well as give the duplicates of the shares. This made the interaction integrated into the story, as the player could choose their own range of the numbers. The final design can be seen in figure 3.4.

Given the change of dimension, the connection between the visual and pragmatic ASSP,

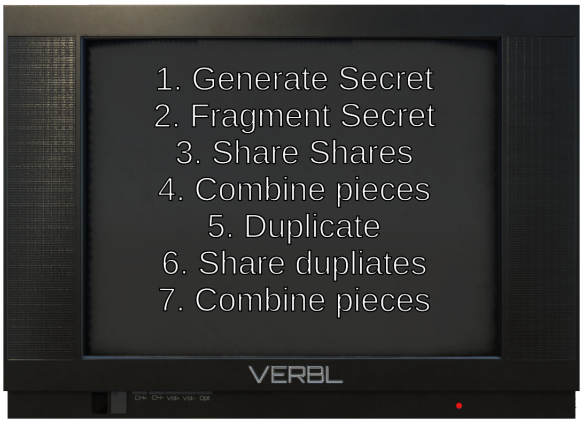

Figure 3.5: The ASSP steps, which would update according to the current progress of the ASSP.

can be difficult to comprehend. To improve this connection, a screen showing the progress of ASSP was added, updating each time a new step was taken. A completed ASSP process can be seen in figure 3.5.

Scripted Interaction

There was some design concern regarding the scripted interaction. Initially, it was planned to be done through a button outside of VR. It fulfills the concept of allowing the user to actively advancing in the story (Giving it the bare minimum of a scripted interaction), in a predefined sequence. It is, however, a contrast to the meaningful interaction, which is planned to work entirely in VR. As to avoid this, the concept was explored in VR. One way of achieving this in VR, is by clicking a button on the controller. while it is in VR, it takes advantage of elements which are not realistic to that of the real world and discarded, ending with the final design, which is the have a virtual button in VR. This design can be seen in figure 3.6. This means that during the scripted condition, when the player is supposed to do the MPC concept themselves, they do so through a button press.

3.4 Story elements

Storyboard

The theme of the story is modelled after the subgenre of crime fiction, **Mystery**. A mystery is defined as a story, in which a puzzle or mystery needs to be solved [16]. It follows the overarching theme well, working with the idea that encryption is a sort of puzzle. The full script for the scripted condition can be seen in Appendix A.1, and for the meaningful in Appendix A.2. A summary is provided here:

> An agent is called in, unsure as of why. He meets Virtua, a flying robot, who tells them that there has been a breach in their security system. The agent will

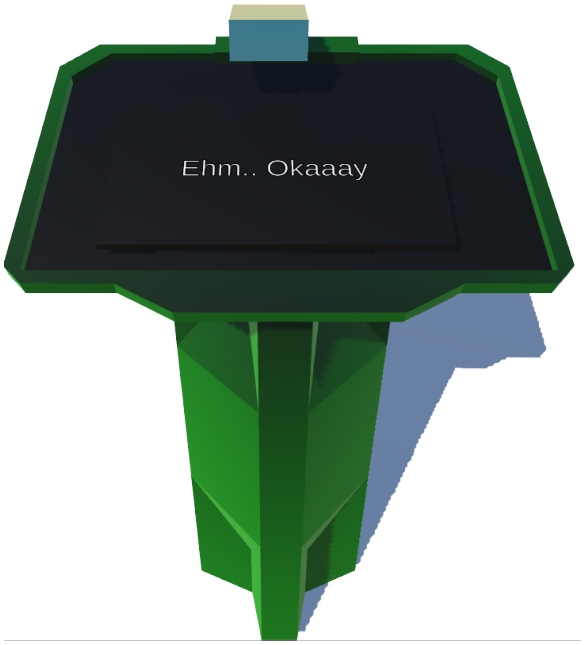

Figure 3.6: The button the player has to press to continue in the story.

need to help fix this issue, and to do so, is sent into a simulation set in 2019. In this simulation, the agent meets Kim, a fellow agent. Kim informs the agent that to solve this case, they need to work together. Kim further states that him, David (Another fellow agent) and the agent each has a latency signal. If they were to find the total sum of all three signals, they could figure out the location of the bandits. However, if they were to send the exact latency signal, Kim fears the bandits may figure out their plan. So instead, they have to use MPC. The agent is shown how to compute ASSP, and afterwards the agent has to perform it themselves. Virtua shows itself again during this stage, and helps the agent perform the ASSP. Once finished, Kim will thank the agent for their help, before the agent is sent back to the lab. David awaits the agent in the lab, thanking the agent for their help, and explains a bit further on how MPC can be used in the future.

The events in the story all leads up the completion of the ASSp. During the completion of the ASSP; the story will differ, depending on it either being the scripted or meaningful condition.

Characters

Each character has their own unique tropes making the stand out, as opposed to that of flat characters with no personality. The characters in the story are as follows; Virtua, Kim and David.

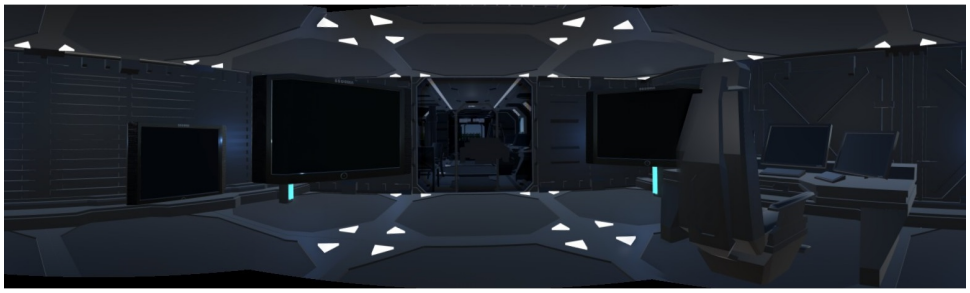

Figure 3.7: Panorama picture of the introduction environment created for the experiment.

Virtua is an inanimate object, modeled after an HTC Vive controller, come to life in this slight Sci-fi experience. Virtua introduces the person to the mission, and helps them later with solving MPC. The character was made with the intention of being slightly dorky and playful. Kim supports the agent during the mission, and explain the concept of ASSP to them. She is only present on an old RCT television. The character was made with the classic a sharp attitude a “no-time for chat”. David awaits the agent after they finish your mission, and congratulates you for a good job on the mission, as well as explaining some use cases for MPC. This character shares a similar attitude to Kim.

Environment

The story is set in a scientific laboratory. Several objects are spread throughout the environment to liven up the place and give it a natural look. These objects include furniture, plants, pillars, computers and alike. The light is emitted from a set of four lamps set in each color of the room, with no additional effects added.

In total, the user goes through three stages, Introduction, The Mission and Conclusion. During the introduction, as seen in figure 3.7, the player is guided on the controls in VR. This consists of pressing the virtual button, and for meaningful condition only, also pressing the trigger and grabbing, moving and placing and object, to ensure they understood the action, a relevant factor in agency, as discussed in section 2.1. During this stage they are also given a brief introduction to the mission, as well as asked the first question in the MPC questionnaire. During the mission, as seen in figure 3.8, the player is told of the reason for the mission, and the explanation of ASSP. After, the participant will have to the MPC themselves, as seen in figure 3.9. Once completed, they will move onto the conclusion, as seen in figure 3.10. Here David will talk about their mission, and lastly the player is asked the last three question of the MPC questionnaire.

3.4.1 Overview of meaningful and scripted condition

The meaningful condition changes the artifact on two occasion, in the beginning, where the user is taught how to grab an object, and during the completion of the ASSP. The interaction during the active ASSP is designed in the following way:

Figure 3.8: Panorama picture of the mission created for the experiment.

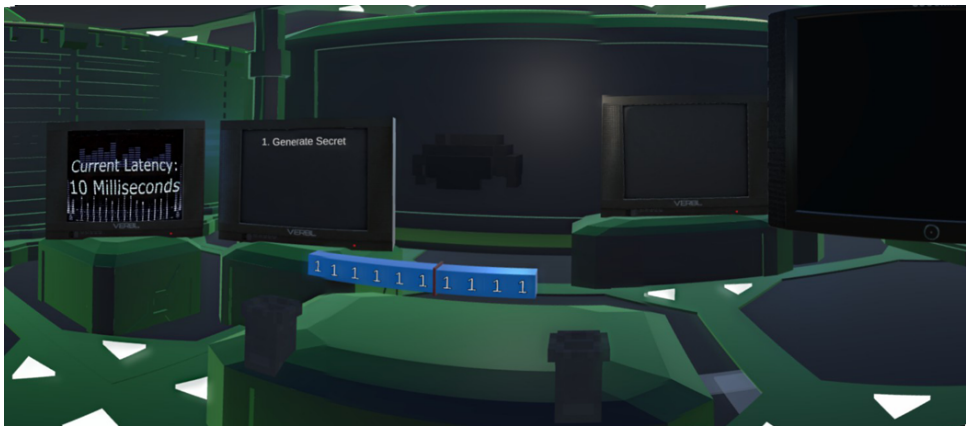

Figure 3.9: Panorama picture for the mission:MPC stage.

Figure 3.10: Picture of the the end stage with David.

1. The player is given a predefined number. They select the points at which the number should be fragmented. They do so, by moving a box symbolizing a "cut". They need to place two cuts, one at a time. They lock the cut in place, through the press of a button.
2. Once they lock the second cut, the bar cut itself into three pieces (The shares), depending on the placements of the cut.
3. The player needs to grab the outermost shares and give it to the two other parties.
4. The process is animated up until the shares are duplicated, at which point the player needs to give the duplicates to each other party again.
5. The rest of the ASSP is animated until the end.

The scripted condition requires no grabbing of objects, hence it is not covered. The scripted interaction during the active ASSP is designed in the following way:

1. The player is given a predefined number. Two cuts, one at a time, move itself to a predefined location. Once the cut has placed themselves, the player continues the process with a press of a button.
2. The process is animated until the player received the two shares from the other parties, at which they press another button to continue.
3. The rest of the ASSP is animated until the end.

Chapter 4

Artifact implementation

The artifact's implementation details are covered in this chapter. Vital scripts, implementation concerns and solutions, 3D models, Audio and video, and designed shaders are presented and discussed.

4.1 Software

The artifact for the experiment, i.e. the software, were developed in the game engine Unity[1]. Some encompassing assets are SteamVR[2] and VRTK[3] were used to build the interactive VR experience. During programming, an HTC Vive head-mounted display was used to test it, but it should scale to any 360 VR display with controllers. The HTC Vive display included its standard wand-like controllers[4] coupled with headphones for audio.

4.2 Code Scripts

4.2.1 StageHandler and LanguageHandler

The most influential script in the program is the StageHandler, and the enumeration (Shortened as enum) Stage. The enum Stage contains all the stages throughout the whole experience as values, an example of this enum can be seen in listing 4.1. The program uses this enum to check the next stage, and to run the appropriate functions for the current stage. The StageHandlers has a variety of functions, from which the current stage can be both be set and retrieved from it. It further has several overloads, so that it can be changed depending on the situation. These include: Setting to specific stage, change after a set amount of time and change to a specific stage, after a set amount of time. By default, the program starts at the

[1] https://unity3d.com/
[2] https://steamcommunity.com/steamvr
[3] https://vrtoolkit.readme.io/
[4] https://www.vive.com/eu/product/

initial stage, in the Stage enum. The program also includes a ManualSkip variable, which determines if the program should continue to the next stage automatically or not. This was used during development. This functionality can be seen in listing 4.2.

```
public enum Stage{
        Setup,
        StartVirtua,
        Virtua01,
        Virtua02,
        Virtua03Script,
        Virtua03SimA,
        ... (57 omitted stages)
        David04B,
        David04C,
        DavidEND,
        EndPanel
    }
```

Listing 4.1: The C♯ implementation for the enum Stage. An example of the start and end stages are given here.

```
    Stage currentStage, tempStage;
    public Stage StartStage;

    public Stage GetStage() {
        return currentStage;
    }

    public void SetStage(Stage scene) {
        if (es.getManualSkip())
            return;
        currentStage = scene;
    }

    public void SetStage() {
        SetStage(GetNextStage());
    }

    public void SetStage(float time) {
        StopAllCoroutines();
        StartCoroutine(WaitTimeBeforeSceneChange(GetNextStage(),
            time));
    }

    public void SetStage(Stage scene, float time) {
        StopAllCoroutines();
        StartCoroutine(WaitTimeBeforeSceneChange(scene, time));
    }
```

```
IEnumerator WaitTimeBeforeSceneChange(Stage scene, float
    time) {
     yield return new WaitForSeconds(time);
     SetStage(scene);
     yield return null;
}
```

Listing 4.2: The C♯ implementation of relevant functionality in StageHandler.

Another prevalent script is the LanguageHandler, allowing with little change, to set the language to another one than English. The process to change language is as follows: Add the new language to the enum Language. Ensure appropriate file name add them to the AudioClip array. Add the new language to the text functions inside LanguageHandler. Through this, the program will be able to change entirely to another language. The reasoning for implementing this sort of functionality, is to make the program more globally accessible, as it can easily be updated to another language. As to how the audio is set, the program searches the finds the current language (Set as an enum), finds the current stage, and finds the AudioClip which names corresponds to the current stage. This functionality can be seen in listing 4.3.

```
public enum Languages {Danish, English };
public Languages Language;

[SerializeField]
AudioClip[] danish, english;
AudioClip[,] languageAudio;
AudioClip ClipToPlay;

void NewAudioClip() {
    int currentLanguage = (int)Language;
    string stageName = sh.GetStage().ToString();
    for (int i = 0; i < danish.Length; i++) {
        if (stageName + " (UnityEngine.AudioClip)" ==
            languageAudio[currentLanguage, i].ToString()) {
             print(stageName);
             ClipToPlay = languageAudio[currentLanguage, i];
        }
    }
}
public AudioClip GetAudioClip() {
    return ClipToPlay;
}

public string KimPanel{ //Example of text function
    get{
        switch (Language){
```

```
                case Languages.English:
                    return "The Mission";
                case Languages.Danish:
                    return "Missionen";
            }
        }
    }
```

Listing 4.3: The C♯ implementation of relevant functionionality in LanguageHandler.

Both the StageHandler and Langauge handler follow the singleton pattern, ensuring it only exists once in the scene, and can easily be accessed by other scripts. The implementation for StageHandler can be seen in listing 4.4

```
    //How it looks in StageHandler Script
   public static StageHandler instance;
   void Awake(){
        if (instance != null){
            Debug.LogError("More than one StageManager in
                scene!");
            return;
        }
        instance = this;
    }
    //Example of calling it from separate script, in the same
       project
    StageHandler sh;
    void Start() {
        sh = StageHandler.instance;
        sh.SetStage(StageHandler.Stage.Setup);
    }
```

Listing 4.4: The C♯ implementation of a Singleton Pattern.

4.2.2 Virtua Talking Motion

Virtua was created deliberately with a simple model without facial features. This was done so that it could easily look as if it was talking, through simple movement. This was achieved through the following progress: 1; Computing the max amplitude of a given clip, 2; Find the current amplitude, 3; Shift the model positions on the Z axis, Rotate the model on the X and Y axis, according to the current amplitude. The direction was, at random, set to negative or positive. This process was computed every 0.2 second, and it would shift the model from its current transform to its new transform through linear interpolation over time. This tantamount to a model that looked as if it was talking, when given a voice clip. The code implementation of this can be seen in listing 4.5

```
//Variables
float soundReactTime = 0.2f;
public int sampleDataLength = 1024;
float currentUpdateTime = 0f;
float clipLoudness;
float[] clipSampleData;
int randomTiltX, randomTiltY;
//Function
currentUpdateTime += Time.deltaTime;
    if (currentUpdateTime >= soundReactTime) {
        currentUpdateTime = 0f;
        aS.clip.GetData(clipSampleData, aS.timeSamples);
        clipLoudness = 0f;
        foreach (var sample in clipSampleData) {
            clipLoudness += Mathf.Abs(sample);
        }
        clipLoudness /= sampleDataLength;
        randomTiltX = Random.Range(-1, 1);
        randomTiltY = Random.Range(-1, 1);
    }

    transform.position = Vector3.Lerp(transform.position, new
       Vector3(0, clipLoudness), Time.deltaTime);
    transform.rotation = Quaternion.Lerp(transform.rotation,
       Quaternion.Euler(clipLoudness * motionMultiplier *
       randomTiltX, clipLoudness * motionMultiplier / 2 *
       randomTiltY + 180, 0), Time.deltaTime);
}
```

Listing 4.5: The C♯ implementation of the talking motion for Virtua.

4.2.3 Write Variables to .txt File

During the experiment, the four questions inquired regarding ASSP were all logged in text files. It would log the following: Participant No., Condition, Question No., Answer. The implementation of this functionality can be seen in 4.6

```
public static void WriteString(int partNo, int cond, int val,
   int question) {
    string fileName = partNo + " " + cond + ".txt";
    string path = "Assets/Textfiles/";
    StreamWriter writer;

    if (File.Exists(path + fileName)) {
        writer = new StreamWriter(path + fileName, true);
    } else {
        writer = File.CreateText(path + fileName);
```

```
        }
        writer.WriteLine(question + " " + val);
        writer.Close();
    }
```

Listing 4.6: The C♯ implementation for saving text files during run-time.

4.2.4 Meaningful vs. Scripted interaction

During the stage "The Mission", the player is opted to perform the MPC themselves. The animations, for both conditions, was created through code, using a series of Transform point and linear interpolation between them. It was done through code, as opposed to doing it using the animator which Unity provides, as the models would change in the meaningful condition, depending on how the user cut the models. The main difference between the condition, is that in the first fragmentation step, the user either presses a button to fragment it and move it to the tubes, whereas in the meaningful condition, the user has to both decide fragmentation points and grab the fragmented pieces and put them in the tubes. The user would also have to add the duplicates to the tubes in the meaningful conditions.

For the interactive elements, the package VRTK makes it so that any object with a collider and rigid body can be made grabbable with a VR controller. Further, the interactive elements are specified to have precise grab, meaning that the transform of the grabbed object moves and rotate around the grabbed point. When grabbing an object and moving it to the tube, VRTK includes a DropZone object, which specified that when a specified object enters the DropZone objects collider, if the user drops the object, its transform will be set to that of the DropZone's.

4.3 3D Models

The majority of the models were imported from the Sci-Fi Styled Modular Pack by Karboosx[5]. The pack included both the building and furniture, which was used for the setting, and to fashion the room into a more realistic setting. The flat screen and the old tv were also imported from asset store. Other than those, a few models were created in MagicaVoxel[6], with texture and pivot point changed slightly in Maya[7] before being imported into Unity. These models include the set of houses used during the showcase of the bandits stealing the unencrypted data, as well as the model for Virtua. It was also used to model the discarded Enigma machine shown in picture 3.1.

[5] https://assetstore.unity.com/publishers/21807
[6] https://ephtracy.github.io/
[7] https://www.autodesk.com/products/maya/overview

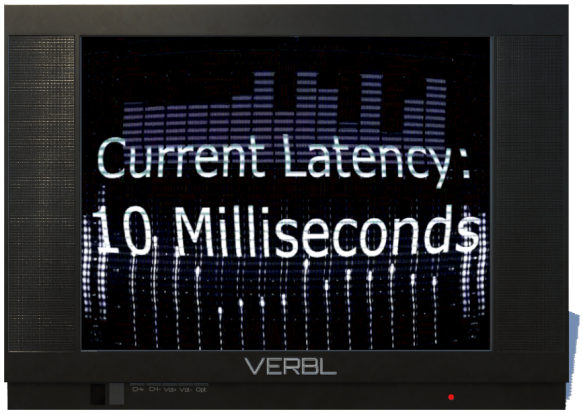

Figure 4.1: The TV showing the current latency at the agents location.

4.4 Audio and Video Clip

The audio was recorded with a handheld microphone, and a camera mounted on top of a tripod. The audio and video files were kept and played individually in the program (As opposed to attaching the audio clip to a video file). This meant that the audio files could be changed to another language, without having to capture new videos. All the videos were also added a TV Simulator effect, which bend the screen slightly outwards to simulate an RCT TV. As for the latency screen, a statistic effect was added with the text "Latency: 10 milliseconds" on top, with the TV simulator effect as well. In this case, the TV simulator was used to a greater degree, playing effects to sway the screen as well as having a slight aperture grill effect. The result can be seen in figure 4.1.

4.5 Shaders

Shaders present themselves in two occasions in the program; The ButtonShader, which is used for all buttons, and the WallsShader, which is used for all of the building's walls, floor, ceiling and objects. The ButtonShader uses a sine wave (Remapped to go from 0-1) over time to control a glowing golden color (#ECCA00) on top of its otherwise blue (#007495) surface, see figure 4.2. As for WallShader, it has three different looks controlled through script, depending on the current stage. During the Introduction and Conclusion scenes, it is black (#00000A), see figure 4.3. During the Introduction stage, at the end, it also changed to a dissolve effect, in which a noise map and a sine wave over time changing a value threshold for displayed parts of the shader, creates an effect where the surrounding walls will be pulsating, see figure 4.4. At the edges of dissolved objects, an outline (#007ACD) was added, to make the effect look slightly more impressive. During the mission stage, the shader was set to black (#00000A), with an added a glowing green (#00FF12), through a sine over time, see figure 4.5.

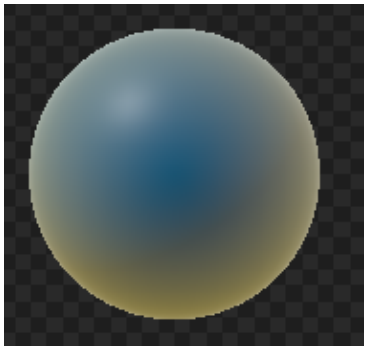

Figure 4.2: The shader used for the buttons.

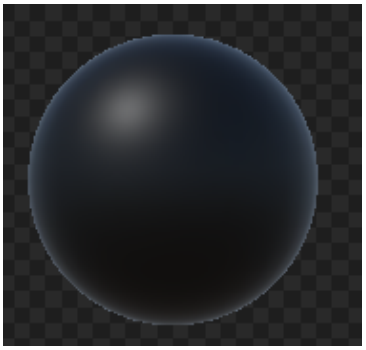

Figure 4.3: The shader during the introduction and the conclusion.

Figure 4.4: The dissolve shader.

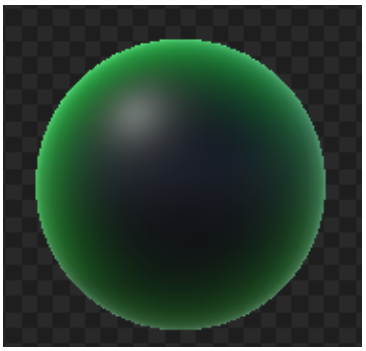

Figure 4.5: The shader used during the mission.

4.6 Artifact run-time

Experiencing the entirety of the story takes approximately, 10:45, with the meaningful condition taking about half a minute longer. As for the meaningful interaction, it takes about 1:30 minutes to complete, with a similar time for the scripted interaction. This means that for the entire of the story, the difference is expected to occur in 14% of its run-time. The time may vary, depending on when the user chooses to continue in stages, so the given times are an approximation. Further, the user can choose to repeat the visual explanation of ASSP, which would add another 2:30 minutes to the run-time.

Chapter 5

Experiment Procedure

To validate if the artifact is able to teach the concept of ASSP, and if there was a difference in player agency and presence between the conditions, an experiment was designed. The following chapter presents the preliminary testing of the artifact, the setup for the experiment, the participants who partook in it, and the procedure in which they were recruited and prepared.

5.1 Preliminary testing

Other than internal testing, the program was presented to two times during development. Firstly, somewhere halfway through the project it was shown to a set of Teknoantropolgy students. At this point only the introduction and partly the mission was finished, with all audio dialogue. The test participants reported that none understood the concept, which led to a stronger focus on making the explanation of the concept in the script clearer. Further, there was a positive response towards the use of spatial sound. The second test was at the end of the project, to determine if there were any oversights, which could affect the experiment. Three Medialogy students went through the prototype, who each managed to do so from start to finish, without error, deeming the prototype was ready.

5.2 Setup of experiment

The experiment was set up in three different locations, all closed rooms with no perceived interference. The room spanned at least 2x2 meters of free space, in which the virtual experiment was set up. A VR Ready MSI laptop was used to run the experiment, which had a constant of 60+ frames per second when running the develop artifact. An HTC Vive with its wand-like controller and built-in headset were used. The set up can be seen in figure 5.1. The experiment is designed to be carried out with one facilitator, who will be monitoring the view of the participant, in case of them getting stuck or asked a question related to the current place at any time during experimentation, and take note of anything of interest. Given

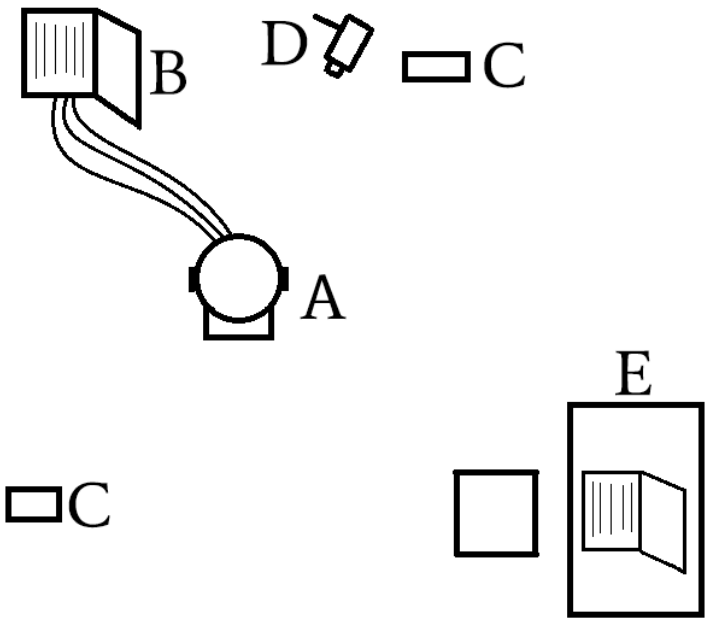

Figure 5.1: A: The participant during the VR experience, with the headset on. B: The laptop which ran the software. C: The HTC Vive base stations. D: The camera filming the participants. E: The laptop to fill out the questionnaire.

that everything run as expected, the participant should be able to complete the whole virtual experience on their own. After, they would be guided to a laptop with the questionnaires on it.

5.3 Participants

29 participants were recruited for this study. Four were discarded due to issues faced during experimentation, such as software failure. The final analyzed sample consisted of 25 participants, 2 female and 23 male, with age ranging from 21 to 28 years [M = 25.52, SD = 1.71]. All participants with severe visual impairments wore corrective glasses/lenses during the experiment. In total, 12 went through the scripted condition, and 13 through the meaningful condition. All participants reported themselves as intermediate to expert at computer experience, and 19 reported to be intermediate to expert of their VR knowledge.

5.4 Procedure

All participants were either students or staff casually recruited at Create, Department of Architecture, Design, and Media, with a large majority (68%) being of Danish nationality. None reported severe motor, hearing or visual impairments, that could not be corrected.

Before entering VR, each participant was given a brief explained that the system was made to test certain interactions in VR. They were given a consent form, in which they gave a written agreement that their inputs during the experiment could be used for analysis, and if they agreed to be recorded through both video and audio. Once completed, they were asked if it was their first-time using VR, and if they were deemed to have none to basic VR experience, they were quickly guided on using the headset and the controllers. They were told a character would guide them in VR, and unless they got stuck, they should try and complete the experience on their own. After having completed the VR experiment, they would immediately be asked to fill out the Player Agency questionnaire and the ITC-SOPI questionnaire.

Chapter 6

Results

The results from the experiment are presented in this chapter. In total, three different questionnaires were used, for MPC, Player Agency and Presence. The MPC results were gathered during the virtual experiment, and the player agency and presence following. For each result, any noteworthy findings are presented, and a graph for the mean and standard deviation for every variable is included. Observations made during the experiment is also presented.

6.1 MPC Results

The MPC questionnaire consisted of four questions. The gathered data is ordinal, non-parametric and unpaired. A table with the arithmetic mean and standard error for each answer, for both conditions, can be seen in figure 6.1. As a side note using a Wilcoxon-Mann-Whitney test, there was found no significant difference between conditions, in any of the questions. Combining both conditions, most participant had a low knowledge of encryption methods (M = 1.96, SD = 1.06). Following the experiment, the general consensus was that they were more aware of encryption method (M = 3.72, SD = 1.1), and a high majority argued they would be able to replicate the APPS (M = 3.8, SD = 1.118). Assuming that a 4+ would mean they were capable of replicating it, a majority (72%) would successfully be able to replicate it. The last question, how the participant felt about their data online, was perceived as low (M = 2, SD = 1.118).

6.2 Player Agency

The Player Agency Questionnaire consisted of 12 questions. The gathered data is ordinal, non-parametric and unpaired. A table with the arithmetic mean and standard error for each answer, for both conditions, can be seen in figure 6.2. A Wilcoxon-Mann-Whitney test indicated that Question 5 ("My inputs had a considerable impact on the events in the game") was greater for meaningful condition (Mdn = 3) than the scripted condition (Mdn = 1), W = 134, p = .001, r = .641, *two-tailed*. The effect size r, is calculated using Rosenthal's formula[36],

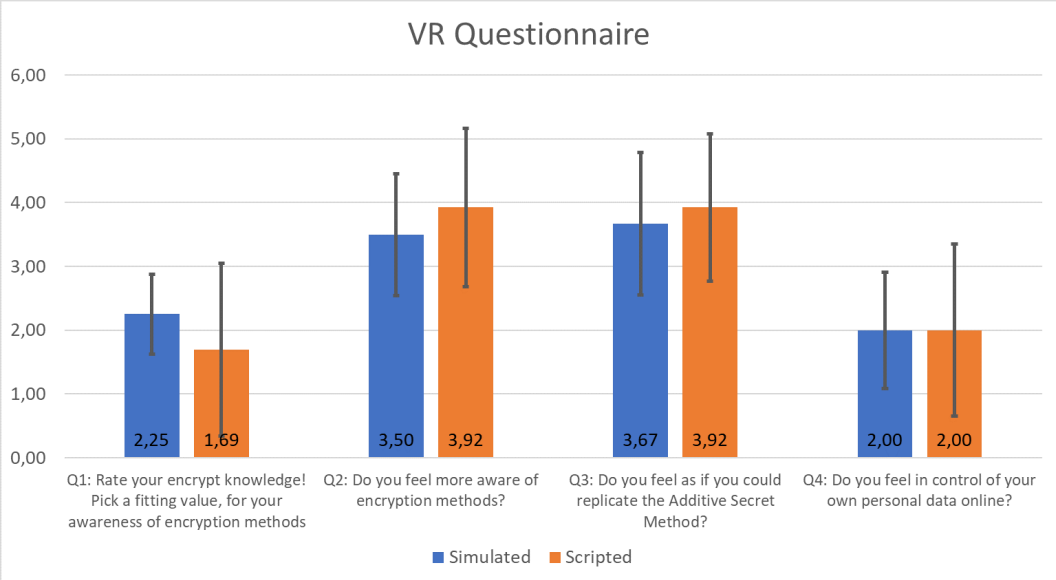

Figure 6.1: The answers for the MPC.

which is an alternative method to Cohen's formula, as Cohen's general assumption of the data being parametric and based on means is violated. No significant difference between the conditions were found for the rest of the questions.

6.3 Presence

As to find if a difference exists between the conditions in presence, ITC-SOPI was employed. The gathered data is non-parametric and unpaired. A table with the arithmetic mean and standard error for related parameters, for both conditions, can be seen in figure 6.3. Using a Chi-square, the different condition does not affect their spatial presence, $c^2(18, N = 25) = .568$, $p = .539$, or their engagement $c^2(11, N = 25) = .14$, $p = .891$. There is a tendency for the ecological value to be greater in the scripted ($M = 3.2$, $SD = .473$), than the meaningful ($M = 2.646$, $SD = .621$), $c^2(4, N = 25) = 2.517$, $p = .066$), and for the negative value to be less in the scripted ($M = 1.291$, $SD = .375$), than the meaningful ($M = 1.807$, $SD = .466$), $c^2(5, N = 25) = 3.059$, $p = 0.028$).

6.4 Observations

A few observations of interest were made during the experimentation. The buttons which the user had to press to continue the story needed an indication, as some of the participants were unsure that they had to press it to progress in the story. Further, one participant found it problematic to complete the tutorial, stating that the relation between Virtua and the VR controller was not clear enough. Lastly, it was noted that some participant would try and

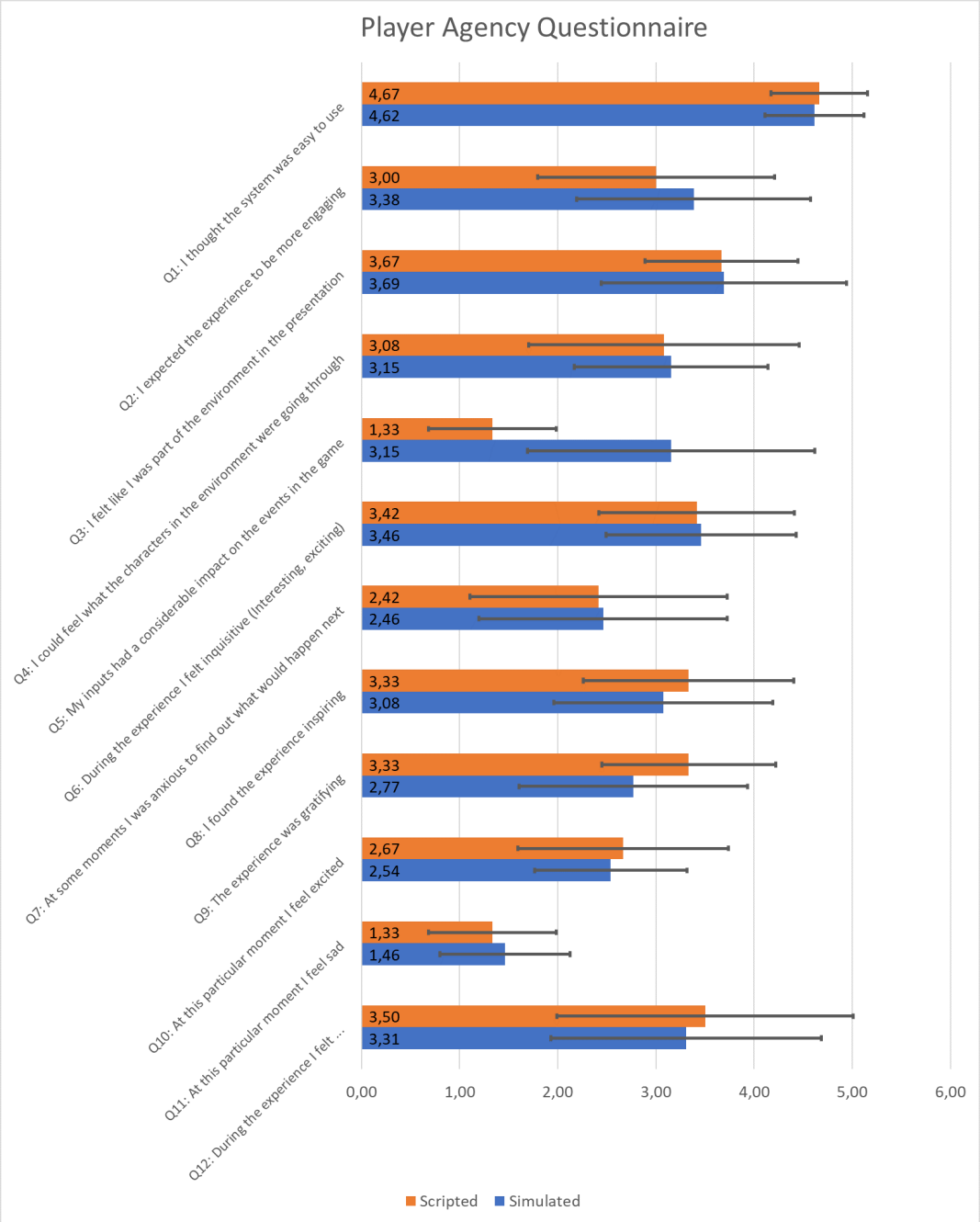

Figure 6.2: The answers for the player agency. Each question includes the mean and standard error

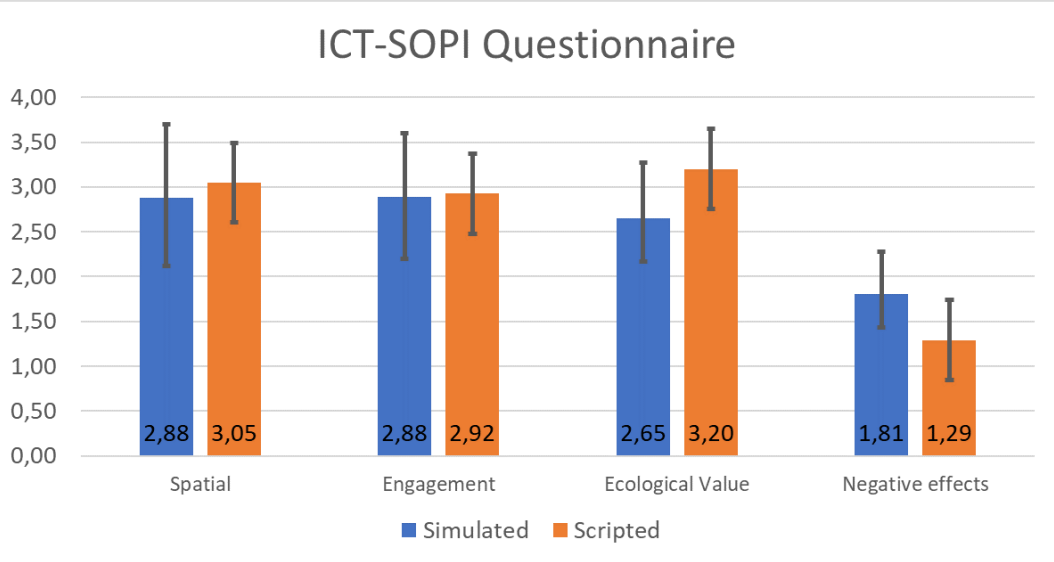

Figure 6.3: The answers for presence.

instinctively try and grab the "cut" piece when they had to complete the ASSP themselves. If they were in the meaningful condition this would work out for them, but in the scripted they would stop themselves once the animation of the ASSP started.

Chapter 7

Discussion

7.1 MPC result

Rounding up, 3 out of every 4 participants understood the concept of ASSP after the experience. It is by no means the ideal result, but still a positive. It indicates the approach for teaching the concept was to a degree successful, and with a bit more work, could be a great tool for teaching the concept. Further, the VR questionnaire further proves that people generally find their data online vulnerable, as also discussed previously, in section 2.5.

7.2 Player Agency results

For the most part, the questions proved insignificant. As presented in section 2.6, the five first question are preconditions for meaningful experiences, arguing that the experience did not affect player agency as a whole. However, question 5 ("My inputs had a considerable impact on the events in the game") shows a strong indication, that a meaningful interaction makes the user gain awareness of their affecting on the story, compared to a scripted interaction. This gives credit to the fact that through the presented definition of a meaningful interaction, a linear story can achieve some aspects of a player agentic experience.

7.3 Presence results

There was no noticeable difference between spatial presence and engagement, which are arguably the most notable aspects of the ICT-SOPI questionnaire. The only finding from this, is that a meaningful interaction does not make a more presence rich experience. Ecological value and Negative Effects showed a tendency towards scripted being the better, with higher ecological value and lower effects. Possibility to why this difference exists, could be due to the focus distance when looking at objects to interact with and the screen.

7.4 Future Work

The findings for MPC indicates that this possible method for teaching MPC. It does not state whether this is an improvement over traditional means, so this study would benefit from a comparison, both to learning MPC through a desktop PC or through a teaching session, ideally spanning the same length as the developed VR experience for this study. Further, given the focus on a story, it would be interesting to see if traditional means would be as exciting as this experience, while still teaching the concept.

While the findings for the meaningful condition are significant, there's a high standard deviation on the result, suggesting that the experience is highly subjective. It suggests that the population the experiment is tested on, can change the findings, thus further testing with a new population would be ideal, to ensure significance of the results.

Another pressing issue is if this finding is significant for other medias, such as on a desktop PC, or if it is tied to VR. The study could be re-created for desktop PC, and tested in a similar manner as to see if the significant difference between the conditions is still present. This would further validate this is a method for achieving player agency.

The experience might also differ, depending on when the meaningful interaction takes place in the story. For this experience, the meaningful interaction is, compared to whole experience, only a small part. But it is set to be the plot of the story, arguing it to be tied to the entirety of the story. The interaction also takes place towards the end of the program, arguing the participants would more easily recall this event, compared to the rest of the experience. Further experimentation with the meaningful interaction in different parts of the story could be of interest, as to see if the findings would differ from the ones presented here.

Lastly, the difference of a scripted interaction vs. a meaningful interaction showed no significant difference on the presence. The meaningful interaction was only a small part of the entire run-time, which could be a reason as to why presence was not affected by the difference in the conditions. It would be of interest to create an application applying several preconditions for a meaningful experience, vs. one without, to find if presence is affected. As it stands now, no connection seems to be present.

Chapter 8

Conclusion

This study evaluates how a meaningful interaction and a scripted interaction affect a player's agency in a story. This study identified factors related to the feel of agency, based on a various experiment and studies on the topic. These findings led to an evaluation player agency, and how one achieves the feel of agency inside a story. Further, Virtual Reality and Multiparty computation are covered, as the media chosen for the story, and as a topic for the story. Player Agency is the main area of research, and it was found a gap existed in current methods for player agentic experience, namely the interaction between player and choice. As such, a meaningful interaction was defined as an integrated part in a story, whereas a scripted interaction would be a predefined sequence, both with a discernible effect on the story's progress. A story was created to test this gap, where the listener of the story would take part in either the meaningful or scripted interaction.

The experience was successful in increasing several participants knowledge of MPC, to a degree in which they felt able to replicate it (72%). Further, participants rated the meaningful experience significantly higher, when questioned about their impact on the events in the story. This suggests that a meaningful interaction significantly affects the awareness of a listener's control of the story, compared to a scripted interaction. As for presence, no significant conclusion was present. There seemed to be a tendency for the ecological values to be higher in the scripted, and for the negative values to be lower. As for negative values, the negative effects might arise from the increased movement in the meaningful condition.

Chapter 9

Resume på dansk

Dette projekt undersøger hvad det betyder at være agent for din egen krop, og hvordan vi kan miste denne følelse, gennem en kritisk vurdering af forskellige studier omkring området. Konklusion af ”Agency” leder til en undersøgelse på hvad ”Player Agency” er, en term der referer til at du som spiller føler du har en aktiv indflydelse på en historie. Mange studier beviser at der er et link mellem person og karakter i spillet, gennem en implicit rolle, som er en del af ”Player Agency”. Et andet fokus, med mindre solid basis, er hvordan spilleren føler dem selv som agent over historien, uden en implicit rolle. Eksperimenter på dette område har prøvet at implementerer en interaktiv fortælling, hvor spilleren kan skifte på fortællingens gang, under dets forløb. De referer til punkterne hvor spileren kan skifte fortællingens gang som ”meaningful actions”, da de har en påvirkning på fortællingen. Resultaterne har generelt været inkonklusive, så dette studie har i stedet for udviklet en anden form for ”meaningful action”, nemlig en ”meaningful interaction”. I stedet for at fokuserer på en historie med forskellige slutninger, er der lavet en lineær historie, men en ”meaningful interaction”. For at teste om ”meaningful interaction” har en påvirkning på en historie, er det sammenlignet med en ”scripted interacition.”. En ”meaningful interaction” er definit som en begivenhed, uafhængigt af resten af fortællingen, som har en synlig effekt på historien, og hvor spilleren har en påvirkning på udkommet af interaktionen. En ”scripted interaction” er ens, undtagen at begivenheden kun har et udkom.

De to versioner af interaktionen er implementeret i en fortælling i Virtual Reality. I løbet af denne fortælling lærer lytteren omkring multiparty computation, en underkategori indenfor kryptering, som omhandler metoder omkring sikkerhed der kræver 3+ personer. Fortælling blev testet på 25 personer, 13 som prøvede versionen med ”meaningful interaction” og 12 som prøvede ”scripted interactiom”. De to versioner blev samlignet, og det konkluderes i dette studie at gennem en ”Meaningful interaction” forøges spillerens bevidsthed omkring deres effekt på historien, som er et af forudsætningerne for at man får en meningsfuld oplevelse.

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Appendix A

Storyboards

A.1 Scripted Condition

Storyboard for MPC(Scripted)_Engl

Panel 1 – VR instruction
Stage: VirtuaPanel
A black screen with the text: The introduction

Stage: StartVirtua
A room that looks like a mechanic lab.
A flying VR Controller appears (Virtua). The user has to look at Virtua to start the next bit
Stage: Virtua01

Virtua:

Hello agent! It's good to have you here, I hope you're ready for the mission! Oh, I almost forgot to introduce myself, I'm Virtua, your Virtual Reality Control Guider!

Onto the briefing of the mission. Oh, wait, can you hear me by the way? My sound module has been acting all up recently. Just touch the button in front of you to talk to me, like so:

Stage: Virtua02

A button, with a text showing "I can hear you", appears in front the of the user. The VR controller will show how to push it. Once the user clicks it, and the scene will continue.
Stage: Virtua03Script

Virtua:

Phew, I was worried for a second it was still broken. Anyway, during this mission, you will be dealing with issues regarding data security. As you might be aware, it has become a large concern as of recent years. So, I will be needing to ask you to assess your own awareness of current encryption methods employed for data security.

Stage: Virtua04
A line of 5 buttons will appear, each with a score and a text saying "Knowledge of current encryption methods employed for data security". Once the user pushes one, the experience continues.
Stage: Virtua05

Virtua:

Ah, you're the perfect candidate then! Okay let me brief you in on the details of the mission. You will be put in a hypothetical scenario set 2019. In this scenario there has been a breach of data security, and you need to assist in fixing it. You will need to…

The controller start the flicker, as if it has a loose connection, particles will appear surrounding the user.
Stage Virtua06

Virtua:

What was that? Are they already sending you in? Wait! But this is way too soon! I haven't yet explained how… bzz tzz (Drag this text bit out – add more concerned sounds etc).

The scene along with the controller fades away.

Panel 2 – The mission
Stage: VirtuaPanel
A black screen with the text: The mission

Stage: StartKim01
A technician room, filled with old RCT Screen, wires, and a dark neon lighting.
On one of the monitors, a female will start to flicker into view. Once the user looks at the screen the person will materialize and talk:
Stage: StartKim02

Kim:

Hello agent, it's good you could make it. I'm Kim, a fellow agent. I assumed Virtua briefed you in on the details of the mission?
Stage: Kim01

Button ("Uhmm")
Stage: Kim02

Kim:

Alright good. Let's get straight to business then, we have little time to waste. We need you to report the latency on one of the monitors in the room. Can you see a screen that shows a certain latency? Try and look around the room to find it!
Stage: Kim03
The user needs to look around and look at a certain screen with the numbers. Once they do, a button will appear .
Stage: Kim04

Button ("Yes, it says…");
Stage: Kim05

Kim:

No! no, don't tell me! There has been a breach in our security. All our data was previously being sent to EncryptCom, who encrypted it and sent it onwards to us. However, recently we found that a group has managed to infiltrate EncryptCom, making the transfer line unsecure! On the big screen you can see us sending data to EncryptCom, represented as numbers. They

encrypt it and send it onwards to us, in the form of a now encrypted message. However, the breach means that the bandits can access the data we are sending without any encryption!

While kim is talking, another screen will flicker on (In vision of user) showing data going from Home, to EncryptCom, to "Us", and halfway through her speech, another connection will be added from EncryptCom, reciving the data, unencrypted.

Stage: Kim06

Button ("I see")
Stage: Kim07

Kim:

This breach is why we need the latency shown. David, my colleague, and I, have both a similar number. By finding the total sum of our three numbers, we should be able to track and locate the group who caused the breach. However, if they were to figure out that we are on their tales, and sending the latency to each other, they will figure out our plan. We therefor need to hide the numbers we are sending each other. We should be able to do this, that is, finding the total sum without sending the individual numbers using the method Additive Secret Sharing.

Stage: Kim08
Button ("Sorry, what again? Addictive Secret Sharing?")
Stage: Kim09

Kim:

Nono, ADDATIVE Secret Sharing. Let me explain. You see, if you have a network of 3 or more people, you can find the total sum, without ever sharing your own number. This number is your secret! In a network of three people, you would take your own number, the secret, and fragment it into three random sizes, which would add up to your original number. These new fragmented pieces are called shares.

Once again, your own number is your secret, and every piece you send to the other members of the network are shares of your secret.

Stage: Kim09A

Let me show you a visual example of this. Look at the big screen. We have three parties, each with one their secret. All numbers are also shown as a bar. The length of each bar corresponds to its number. For the sake of understanding, I have predicted the total sum of all secrets. Ideally using additive secret sharing we will arrive at this number, without actually showing our secrets. Got it?

The screen next over will show the number. The number will then show a bar below it. The number will increase and decrease, to show the bar increasing in length and decreasing with it. After, two random cuts will be inserted, separating the bar into 3 pieces, with their new values displayed shortly.

Stage: Kim09B
Button -> random OK response

Stage: Kim09C

By making two random cuts on our bar, we would get three randomly sized pieces, adding up to our original number. The original bar is your secret, and once cut into pieces, these are your shares. Do you follow?

Stage: Kim09D

Button -> random OK response

Stage: Kim09E

Take the shares, and give one to the each other individuals in the network. The others will do likewise.

Stage: Kim09F

Button -> random OK response
Stage: Kim09G

You should now possess your own share, as well as two new ones. Now, we add them all together.

Stage: Kim09H

Button -> random OK response
Stage: Kim09I

We duplicate the newly added number for each party in the network, and send it to them, while keeping one for ourselves. Once again, the others will do the same.

Stage: Kim09J
Button -> random OK response
Stage: Kim09K

Stage: Kim09L

Through this, you will end up with the combined value of all numbers in the network! Try and see if it matches the predicted value!

Now why would we do this? Because using this method we would never share our secret, that is our original number, with anyone! It will remain hidden from all the other parties in the network, which is what we desired. We only ever shared the shares derived from the secrets.

If you feel like you still don't understand the method, please do ask me to repeat it, I would be happy to do so! Otherwise, you will need to perform this method yourself!

Stage: Kim10

Button ("Okay, let us try it!")
Button ("Please repeat it") -> Jumps to Kim

Panel 3 – MPC
Virtua flickers into existence again, to support one, to complete fulfill MPC.

Stage: StartMPC01

Virtua:
Over here, over here! (Repeat until user looks)

Stage: StartMPC02

Several things will spawn around the screen with the latency number, in order to complete MPC.
Stage: MPC01

Virtua:
*I managed to superimpose an almost identical 3D model of myself into this simulation! Impressive right? Sometimes, you *have* to do amazing things when people don't keep their time schedules! Tsh. But nevertheless, let us get straight to it. So now we have to latency, and we need to give it the others, using additive secret sharing. To do so, we firstly need to fragment this number into three pieces.*

Stage: MPC02ScriptA

The number will come out of the screen, and change into bar equals it size. Next, it slices itself into three unequal sized pieces.

Stage: MPC02ScriptB

Button ("Okay! Now I have the fragmented number")

Stage: MPC02ScriptC

Virtua:
Good! Next we need to send one of our secrets to David and Kim, while they will do the same.

Stage: MPC02ScriptD

Two of the secrets are put into two separate tubes, and disappear. After, two new pieces will appear, coming from the pipes.

Stage: MPC02ScriptE

Button ("Now I have my own secret, and David and Kim's secret")
Stage: MPC02ScriptF

Virtua:
Correct, next we need to add them together, and send it back to them. Meanwhile they will do the same! Let me add the numbers for you... There we go, okay, and duplicate it three times… Done! Now let us send it onwards, to them!

Stage: MPC02ScriptG
The new number will duplicate itself and go into each tube once again. Similarly, two new bars will come up, and attached to the original bar, and transform into a number once again
Stage: MPC02ScriptH

Button ("I have the final number now")

Stage: MPC03

Virtua:
Okay I hear the others are done on their part, they are sending over their number. Now we add their numbers to our, and… bam! We have the number we need, without ever sharing our original number! This number is the total of all the numbers combined. Okay, I´m done here, good job! We make a great team eh?

Stage: MPC04

The TV with Kim flickers into view again, awaiting the user to look at her, giving audio queues until the user looks.

Stage: MPC05

Kim:

I have received the number! You did well, this can't be your first time on the scene can it? In any case, we can now locate the bandits, and solve this issue once and for all!

Stage: MPC06
Scene dims slightly
Stage: MPC07

Button ("End Simulation")
Panel 4:
Stage: VirtuaPanel
A black screen with the text: The conclusion

Stage: David01
The previous room fades out, and the user is returned to the lab in Panel 1. David will be present, maybe in person or a screen, depending on time for me to implement.
Stage: David02

David:

You did well agent! My name is David. I hope this simulation has made you more aware of methods to secure data. In your daily life, your personal data gets sent to third parties all the time. They keep all this data in one place, meaning that a single breach means thousands of personal information leaked. However, through schemes such as Addetive Secret Sharing, we can avoid this

Stage: David03
Running on a screen, is the numbers used in the previous simulation. It shows your number, as well as the others, and how the average was computed for each individual. It also shows a situation where the number is sent directly to a third-party, which has been compromised.
Stage: David04

David:

Through it, instead of relying on a single third-party to secure our data, we all become directly part of securing it, reducing the means for data leaks immensely. Instead of data being centralized at one point, it would be decentralized. In the future, this can be a possible method for securing data, giving the people the information necessary for services to run, but without feeling our data taken away unwanted. Currently, at Aalborg University the research project SECURE is working towards making decentralized information sharing the future, adding more tools in toolbox for securing data.

Oh and one last thing, please take your time to answer the following questions, for us to analyze if this experience has been helpful to you.

//STAGES TO BE DECIDED

A line of 5 buttons will appear, each with a score and a text saying “Knowledge of current encryption methods employed for data security”. Once the user pushes one, the experience continues.

Thoughts
Furhter buttons will be added, rating specifics of MPC, to see how well they understood it.
Stage: DavidEND

David:

Thank you! I hope you have enjoyed this experience! I will say our goodbyes here.

The scene fades, and a hovering white text appears.
Panel 5 – The end
A text following the HMD shows following:

Thanks for playing!
This experience was designed and developed by: Stefan Tanderup
It was made as a part of my Master Thesis for Medialogy, at Aalborg Univeristy.
It was supervised by Martin Kraus, and created in collaboration with the research project SECURE.
#SecureOurData

Please take off your headset.

A.2 Meaningful Condition

Storyboard for MPC(Sim)_Engl

Panel 1 – VR instruction
Stage: VirtuaPanel
A black screen with the text: The introduction

Stage: StartVirtua
A room that looks like a mechanic lab.
A flying VR Controller appears (Virtua). The user has to look at Virtua to start the next bit
Stage: Virtua01

Virtua:

Hello agent! It's good to have you here, I hope you're ready for the mission! Oh, I almost forgot to introduce myself, I'm Virtua, your Virtual Reality Control Guider!

Onto the briefing of the mission. Oh, wait, can you hear me by the way? My sound module has been acting all up recently. Just touch the button in front of you to talk to me, like so:

Stage: Virtua02

A button, with a text showing "I can hear you", appears in front the of the user. The VR controller will show how to push it. Once the user clicks it, and the scene will continue.
Stage: Virtua03SimA

Virtua:

Phew, I was worried for a second it was still broken. Anyway, I need to teach you a few things. So, follow my instruction. On your controller you have a trigger, please press it. This is the one I'm talking of.

Stage: Virtua03SimB

Virtua will show the button that needs to be pressed. Once the player presses it, the stage continues.

Stage: Virtua03SimC

Virtua:

You're quick! Good! Using the trigger, you can grab and interact with objects in the scene! It's as easy as so, you put your controller in the object, and push the trigger to grab it. Move the box like I do!
Stage: Virtua03SimD

Virtua will show the How to grab and move an object. The player has to repeat its movement, to continue.

Stage: Virtua03SimE

Virtua:

That's all! Now onto the mission. You will be dealing with issues regarding data security. As you might be aware, it has become a large concern as of recent years. So, I will be needing to ask you to assess your own awareness of current encryption methods employed for data security.

Stage: Virtua04

A line of 5 buttons will appear, each with a score and a text saying "Knowledge of current encryption methods employed for data security". Once the user pushes one, the experience continues.

Stage: Virtua05

Virtua:

Ah, you're the perfect candidate then! Okay let me brief you in on the details of the mission. You will be put in a hypothetical scenario set 2019. In this scenario there has been a breach of data security, and you need to assist in fixing it. You will need to…

The controller start the flicker, as if it has a loose connection, particles will appear surrounding the user.

Stage Virtua06

Virtua:

What was that? Are they already sending you in? Wait! But this is way too soon! I haven't yet explained how… bzz tzz (Drag this text bit out – add more concerned sounds etc).

The scene along with the controller fades away.

Panel 2 – The mission

Stage: VirtuaPanel

A black screen with the text: The mission

Stage: StartKim01

A technician room, filled with old RCT Screen, wires, and a dark neon lighting.

On one of the monitors, a female will start to flicker into view. Once the user looks at the screen the person will materialize and talk:

Stage: StartKim02

Kim:

Hello agent, it's good you could make it. I'm Kim, a fellow agent. I assumed Virtua briefed you in on the details of the mission?

Stage: Kim01

Button (“Uhmm”)
Stage: Kim02

Kim:

Alright good. Let’s get straight to business then, we have little time to waste. We need you to report the latency on one of the monitors in the room. Can you see a screen that shows a certain latency? Try and look around the room to find it!

Stage: Kim03
The user needs to look around and look at a certain screen with the numbers. Once they do, a button will appear .
Stage: Kim04

Button (“Yes, it says…”);
Stage: Kim05

Kim:

No! no, don’t tell me! There has been a breach in our security. All our data was previously being sent to EncryptCom, who encrypted it and sent it onwards to us. However, recently we found that a group has managed to infiltrate EncryptCom, making the transfer line unsecure! On the big screen you can see us sending data to EncryptCom, represented as numbers. They encrypt it and send it onwards to us, in the form of a now encrypted message. However, the breach means that the bandits can access the data we are sending without any encryption!

While kim is talking, another screen will flicker on (In vision of user) showing data going from Home, to EncryptCom, to “Us”, and halfway through her speech, another connection will be added from EncryptCom, reciving the data, unencrypted.

Stage: Kim06

Button (“I see”)
Stage: Kim07

Kim:

This breach is why we need the latency shown. David, my colleague, and I, have both a similar number. By finding the total sum of our three numbers, we should be able to track and locate the group who caused the breach. However, if they were to figure out that we are on their tales, and sending the latency to each other, they will figure out our plan. We therefor need to hide the numbers we are sending each other. We should be able to do this, that is, finding the total sum without sending the individual numbers using the method Additive Secret Sharing.

Stage: Kim08
Button (“Sorry, what again? Addictive Secret Sharing?”)
Stage: Kim09

Kim:

Nono, ADDATIVE Secret Sharing. Let me explain. You see, if you have a network of 3 or more people, you can find the total sum, without ever sharing your own number. This number is your secret! In a network of three people, you would take your own number, the secret, and fragment it into three random sizes, which would add up to your original number. These new fragmented pieces are called shares.

Once again, your own number is your secret, and every piece you send to the other members of the network are shares of your secret.

Stage: Kim09A

Let me show you a visual example of this. Look at the big screen. We have three parties, each with one their secret. All numbers are also shown as a bar. The length of each bar corresponds to its number. For the sake of understanding, I have predicted the total sum of all secrets. Ideally using additive secret sharing we will arrive at this number, without actually showing our secrets. Got it?

The screen next over will show the number. The number will then show a bar below it. The number will increase and decrease, to show the bar increasing in length and decreasing with it. After, two random cuts will be inserted, separating the bar into 3 pieces, with their new values displayed shortly.

Stage: Kim09B

Button -> random OK response

Stage: Kim09C

By making two random cuts on our bar, we would get three randomly sized pieces, adding up to our original number. The original bar is your secret, and once cut into pieces, these are your shares. Do you follow?

Stage: Kim09D

Button -> random OK response

Stage: Kim09E

Take the shares, and give one to the each other individuals in the network. The others will do likewise.

Stage: Kim09F

Button -> random OK response

Stage: Kim09G

You should now possess your own share, as well as two new ones. Now, we add them all together.

Stage: Kim09H

Button -> random OK response

Stage: Kim09I

We duplicate the newly added number for each party in the network, and send it to them, while keeping one for ourselves. Once again, the others will do the same.

Stage: Kim09J

Button -> random OK response

Stage: Kim09K

Stage: Kim09L

Through this, you will end up with the combined value of all numbers in the network! Try and see if it matches the predicted value!

Now why would we do this? Because using this method we would never share our secret, that is our original number, with anyone! It will remain hidden from all the other parties in the network, which is what we desired. We only ever shared the shares derived from the secrets.

If you feel like you still don't understand the method, please do ask me to repeat it, I would be happy to do so! Otherwise, you will need to perform this method yourself!

Stage: Kim10

Button ("Okay, let us try it!")
Button ("Please repeat it") -> Jumps to Kim

Panel 3 – MPC

Virtua flickers into existence again, to support one, to complete fulfill MPC.

Stage: StartMPC01

Virtua:
Over here, over here! (Repeat until user looks)

Stage: StartMPC02

Several things will spawn around the screen with the latency number, in order to complete MPC.

Stage: MPC01

Virtua:
*I managed to superimpose an almost identical 3D model of myself into this simulation! Impressive right? Sometimes, you *have* to do amazing things when people don't keep their time schedules! Tsh. But nevertheless, let us get straight to it. So now we have to latency,*

and we need to give it the others, using additive secret sharing. To do so, we firstly need to fragment this number into three pieces.

Stage: MPC02SimA

Virtua:
I've changed the latency number to be represented as a bar. Each cube is equal to a 1, adding up to the total latency. Using your controller, you can slice the bar into three pieces. I'll highlight the cuts in the bar. Using your controller, you can move them around, one at a time, and place it where you find fitting. Just grab the cut, and mov it to your desired location. Once satisfied, press the button "lock cut". You will have to repeat this once, to get the three pieces.

The number will come out of the screen, and change into bar equals to its size. The player has to use their controller to place the cuts in the bar, one at a time.

Stage: MPC02SimC

Virtua:
Okay great! Now that they are cut, we need to give the two others a piece each. Put the number in the tubes, and they will be sent to them.

Stage: MPC02SimD

The player has to take two of the bars and put in the tubes to advance.
After having put them in, two numbers will be returned through tubes next to the other ones.
They new numbers will be placed close to the one you had left.

Stage: MPC02SimE

Virtua:
Perfect! We're almost done. Let me add the numbers for you… There we go… okay, and duplicate it three times… Done! Okay, and now, give the new number to the two others once again, like before, and they will do likewise.

Stage: MPC02SimF

The player takes two of the duplicates and put down each town, same as last time. After some time, the two new numbers will arrive, and attach themselves to your number.

Stage: MPC03

Virtua:
Okay I hear the others are done on their part, they are sending over their number. Now we add their numbers to our, and… bam! We have the number we need, without ever sharing our original number! This number is the total of all the numbers combined. Okay, I´m done here, good job! We make a great team eh?

Stage: MPC04

The TV with Kim flickers into view again, awaiting the user to look at her, giving audio queues until the user looks.

Stage: MPC05

Kim:

I have received the number! You did well, this can't be your first time on the scene can it? In any case, we can now locate the bandits, and solve this issue once and for all!

Stage: MPC06

Scene dims slightly

Stage: MPC07

Button ("End Simulation")

Panel 4:

Stage: VirtuaPanel

A black screen with the text: The conclusion

Stage: David01

The previous room fades out, and the user is returned to the lab in Panel 1. David will be present, maybe in person or a screen, depending on time for me to implement.

Stage: David02

David:

You did well agent! My name is David. I hope this simulation has made you more aware of methods to secure data. In your daily life, your personal data gets sent to third parties all the time. They keep all this data in one place, meaning that a single breach means thousands of personal information leaked. However, through schemes such as Addetive Secret Sharing, we can avoid this

Stage: David03

Running on a screen, is the numbers used in the previous simulation. It shows your number, as well as the others, and how the average was computed for each individual. It also shows a situation where the number is sent directly to a third-party, which has been compromised.

Stage: David04

David:

Through it, instead of relying on a single third-party to secure our data, we all become directly part of securing it, reducing the means for data leaks immensely. Instead of data being centralized at one point, it would be decentralized. In the future, this can be a possible method for securing data, giving the people the information necessary for services to run, but without feeling our data taken away unwanted. Currently, at Aalborg University the research project SECURE is working towards making decentralized information sharing the future, adding more tools in toolbox for securing data.

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//STAGES TO BE DECIDED

A line of 5 buttons will appear, each with a score and a text saying “Knowledge of current encryption methods employed for data security”. Once the user pushes one, the experience continues.

Thoughts
Furhter buttons will be added, rating specifics of MPC, to see how well they understood it.
Stage: DavidEND

> *David:*
>
> *Thank you! I hope you have enjoyed this experience! I will say our goodbyes here.*

The scene fades, and a hovering white text appears.
Panel 5 – The end
A text following the HMD shows following:
Thanks for playing!
This experience was designed and developed by: Stefan Tanderup
It was made as a part of my Master Thesis for Medialogy, at Aalborg Univeristy.
It was supervised by Martin Kraus, and created in collaboration with the research project SECURE.
#SecureOurData

Please take off your headset.