Locomotion Techniques in VR for Complex and Extensive Environments

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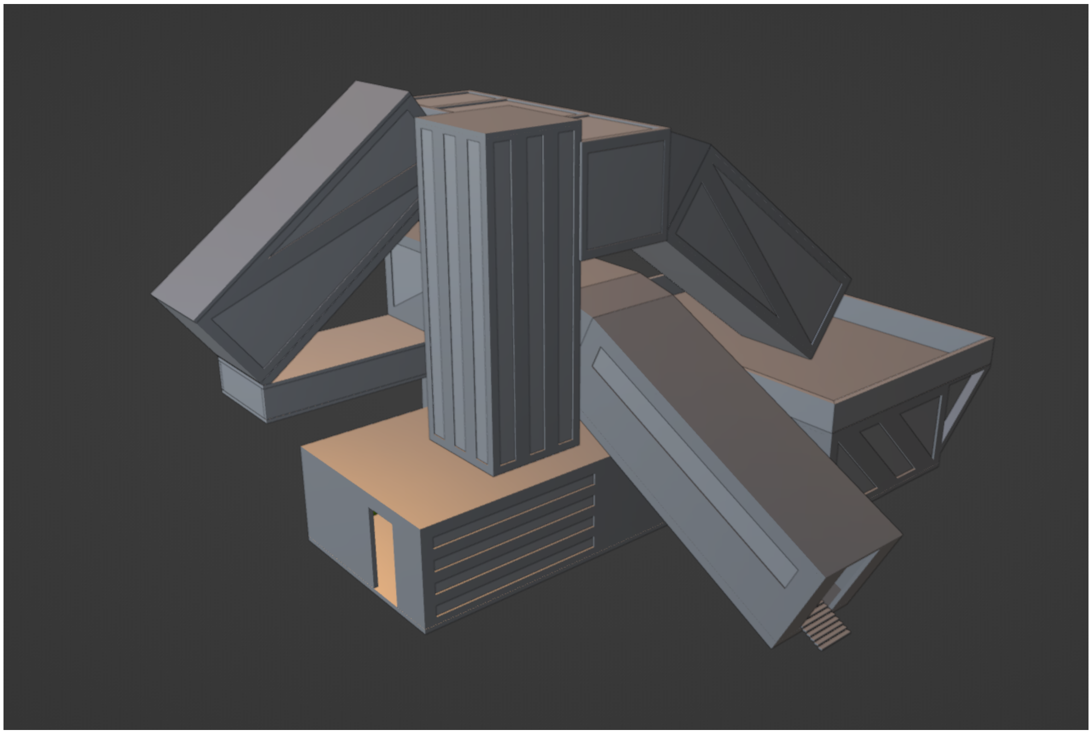

Fig. 1. Escape room building with a complex and nested architecture in Blender.

Virtual Reality (VR) enables a realistic immersion in virtual game environments. Although there are theoretically no limits for virtual content, physical locomotion in VR becomes problematic, when real space is limited. The aim of this research is to find a suitable VR locomotion technique for our game Escapers, in which the virtual space is more extensive than the physical one. In a user study with N = 15 participants, we evaluated the sense of presence, orientation retention, and handling of teleportation. The results show a strong sense of presence using teleportation, despite visual jumps after teleporting to another place. It was also shown that the majority retained orientation and perceived the handling of teleportation as easy and intuitive. Consequently, the choice of teleportation as locomotion technique is considered an effective method for VR games with a complex and spacious environment.

1 INTRODUCTION

In conventional games, players use input devices such as mouse and keyboard, or a gaming controller while seeing the virtual world through a computer display [4]. Thus, virtuality is clearly separated from the real world, which makes navigation less challenging than in VR games [5]. In VR, display and interaction systems (e.g. head-mounted displays and controllers) are intended to provide a surrounding and extensive illusion of reality [14] and players should be immersed in this virtual environment. Immersion is a characteristic of VR experiences, but also brings challenges to the design of locomotion. Since people have learned from reality how physical objects behave and how to interact with them, similar expectations arise for the virtual space [4]. For example, the expectation that the player can move through virtuality by real walking, the most natural way to navigate in VR [15]. However, if the physical space is smaller than the virtual playground, locomotion in VR becomes problematic [5, 6, 15] and natural walking is not suitable as locomotion technique.

Although locomotion is not the primary task in most games, it enables the player to accomplish the primary task [13] and is consequently a common and necessary activity in VR [6, 13, 15]. According to the VR developer company Oculus, a comfortable and efficient locomotion design is essential to the success of a VR game, maximizes the user experience and minimizes discomfort [11].

The aim of this research is to find a suitable VR locomotion technique for games, in which the virtual space is more extensive than the physical one. In this paper, we first discuss strengths and weaknesses of various VR locomotion techniques. Afterwards, we present the implementation of the most suitable technique in our VR escape

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room game as well as our user study results. In our study, we investigate, whether the chosen technique is suitable for our game Escapers, in which an abstract environment has to be explored (see Figure 1).

2 RELATED WORK

In this section we discuss various locomotion techniques, compare them based on previous research and present our research hypothesis.

2.1 Locomotion Techniques

In general, two types of locomotion are classified in VR [1, 11]. Physical locomotion is when the camera matches the physical movement of the headset, and the perspective of the viewer in the virtual world matches the exact movement of the headset in the real world. As mentioned earlier, physical locomotion is the most natural way to move around in VR [15], but is subject to some challenges when physical space is confined [5, 6, 15].

When using artificial locomotion, the camera moves independently of the position of the headset [1, 11]. As a result, the player can move in the virtual world, but does not necessarily make the same move in reality. For example, the player might walk, run, or drive in VR while sitting quietly on a chair in real life. Although physical locomotion is more natural and therefore more immersive [15], artificial locomotion brings many advantages that players in confined environments can benefit from. For example, riding a virtual roller coaster or walking through an abstract architectural building becomes possible.

However, artificial locomotion can be understood as a collection of different techniques that attempt to approximate physical locomotion [10, 12]. Oculus and researchers in the field of VR have identified some techniques that are presented below:

- The avatar movement technique is named in Oculus' guidelines and used by a large majority of VR games today [11]. The technique is also referred to as controller-based [1] or gamepad locomotion [10], because the input is similar to a classic game controller [5]. Players can move their character by using a joystick or a touchpad.
- In the environmental movement technique, the player stands on a specific section and the environment moves when that section is completed or the player wants to leave it [11]. This section could be a moving platform or a small room with a transition when the player exits to the next room. Frommel et al. describe a similar technique of automatic locomotion, where the locomotion and direction of the player is automated by the game logic [5]. The advantage of these techniques is that the movement is automated in the game and therefore the player only needs a small interaction radius.
- Teleportation has become increasingly popular for a wide range of applications [12]. The player points in the virtual space where he would like to be and the viewpoint is immediately teleported to this position [1]. In contrast to the other techniques, the movement is noncontinuous and is interrupted by visual jumps.
- In addition, there are other creative and partly abstract locomotion techniques that are applied in VR games. For example, steering movement, for movement in virtual vehicles [11], or the virtusphere technique, in which the player is inside a sphere in the real world that rotates to match the user's steps in VR [10]. A final example of a creative approach is a room-scale-based design where the virtual space is limited to the size of the real environment [1].

2.2 Evaluation and Comparison

Based on user tests, controller-based locomotion is rated with a high usability score and is easy to use due to the users' familiarity with controllers [1]. The advantage is that real and virtual movements are no longer coupled and players can focus on their task in VR. However, many subjects also experienced dizziness [1]. This phenomenon is called motion sickness caused by the conflict between the vestibular and visual system [8]. The findings can be supported by another study by Dorado et al. in which the subjects were asked to climb stairs in VR with a controller-based locomotion technique. 20 of 22 subjects felt discomfort climbing stairs and most of them felt sick after less than two minutes [3].

With teleportation, subjects experienced significantly less motion sickness, and if they did, it occurred with less intensity [1]. In addition, the fast navigation was rated positive, but the resulting abrupt changes led to a break in the player's sense of immersion. Wang et al. also conclude that frequent use of teleportation breaks presence [15]. However, they also consider teleportation to be an effective method for exploration and navigation. Another study by Mayor et al. analysed different locomotion techniques in virtual environments [9]. Teleportation and room-scale-based locomotion resulted in less motion sickness than steering locomotion with a gamepad. In contrast, another study by Cliften et al. found that although teleportation produced less motion sickness than steering motion on average, 38% of subjects with teleportation experienced more motion sickness [2].

An explanation for the conflicting results in some cases is given by the work of Sarupuri et al. who point out that each technique is differently well suited for different scenarios, and has to be tested for different test environments and on different tasks [13]. Consequently, not every technique fits every application and it has to be tested whether the chosen technique fits the virtual environment and the task. This is supported by a survey in 2021, which asked 14 international VR companies which locomotion technologies they use the most [9]. The results show that there is not one perfect technique, the VR applications are 27.08% designed using room-scale-based locomotion, 25.01% using controller-based locomotion, and 20.83% using teleportation.

2.3 Hypotheses

Since the research goal is to find a suitable locomotion technique for an escape room game that takes place in an extensive and abstract building, we use artificial locomotion techniques, because of the confined space in reality.

Due to the specific setting of the building, a room-scale-based locomotion design cannot be applied. Moreover, the player should be able to explore the environment freely in the escape room, so automated locomotion and environmental movement are inappropriate.

The controller-based locomotion would fit the requirements of the game, but several studies showed that motion sickness occurs with this kind of locomotion [1–3].

The teleportation technique also fulfills the requirements of the game. Overall, it is rated easy, fast and effortless, plus there is little evidence of motion sickness [12]. It is assumed:

H1: The handling of locomotion with teleportation is easy and intuitive.

However, the visual jumps interrupt the flow in the game and thus the feeling of presence is affected [1, 12]. In addition, the players may have to reorient themselves after a jump [11]. It is also assumed:

H2: Teleportation will lead to disorientation and a low sense of presence.

3 METHOD

3.1 Project Background and Overall Research Objective

This paper is the result of an interdisciplinary game project between designers and developers working with different tools. The goal of the developers was to transfer an architectural design model into a game engine and to find a process to create a playable game environment out of the architectural abstract building (see Figure 2). This game environment should finally be experienced immersively as an escape room in VR. The research area of this paper is limited to finding a suitable locomotion technique in VR for this building.

3.2 Game Prototype and Choice of Locomotion

The architectural base for our game Escapers was created by the designers with the 3D modeling software Rhinoceros 3D. To ensure efficient performance in the game engine Unity and in VR, the architectural model was rebuild and heavily modified in the computer graphics software Blender (see Figure 1).

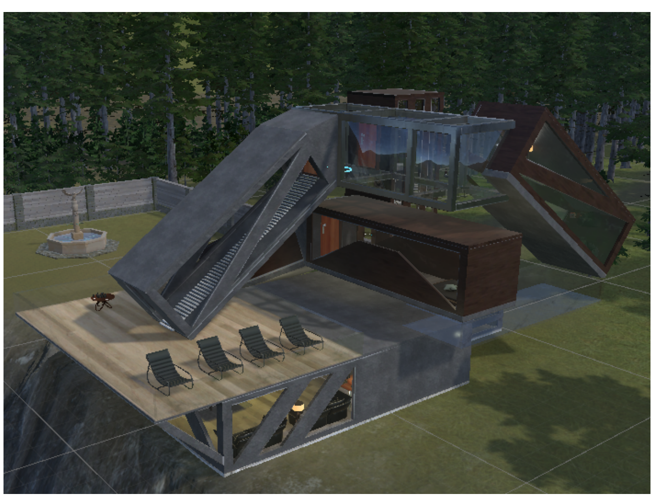

Fig. 2. Screenshot of the escape room in Unity.

As related work in 2.2 and 2.3 has shown, there are some limitations in choosing a suitable technique for locomotion. We decided to use teleportation. Due to the complex and nested architecture of the building, a spiral staircase, rooms with inclination and limited physical space, a room-scale-based or a controller-based locomotion technique is not suitable for our game Escapers. A crucial reason against controller-based were the results of several studies that indicated the occurrence of motion sickness [1–3].

The game prototype uses OpenXR for the integration of VR in Unity and the OpenXR Toolkit for further VR features. For the development of the game and the user study, an Oculus Rift was used with two handheld controllers. In the game, the left thumbstick triggers the teleportation feature. To activate the preview of the next jump, the player has to move the thumbstick forward out of its center position. A blue arc appears that shows the target position of the next teleport. The teleportation is executed when the thumbstick is released quickly and is cancelled when the stick is gently brought into the center position. As it is recommended in the Oculus guidelines [11], the game has a predefined area where the player can teleport back and forth. When players enter the spiral staircase, they are teleported to the upper or lower floor. The other three directions of the left thumbstick were used to quickly rotate the virtual character. By bringing the thumbstick to the left or right, the player turns 90° to the respective direction. Moving the thumbstick backwards, the player immediately turns 180°.

The locomotion with teleportation was complemented by physical locomotion for interaction with close objects, e.g. grabbing something or enter a door lock combination. To grab something, players have to bring their virtual hand close to an object and press a button, causing it to be lifted. As soon as the players release the button, the object falls back to the ground.

Around these mechanics a simple escape room game was build. The players spawn in the highest room of the building and have to find a way out. To open doors, a combination of three digits is needed. These digits are hidden by puzzle exercises that need to be completed, e.g. playing beer pong or adjusting the time to find a digit combination in the shadows.

3.3 User Study

To evaluate the teleportation hypotheses, a user study was conducted. The participants were visitors of a game exhibition, willing to test the game and participate in the user test, as well as agree to the collection of their data. Nine subjects are students in the field of computer science and design, while three subjects work at the university. Besides, there were two software developers and one school student among the subjects. A total of N = 15 subjects participated in the user study, of which eight were male and seven were female. The mean age was 24.93 (SD = 8.40) years, with an age range of 19 to 51 years. Overall, 10 participants reported having already tried VR applications, of which three use VR very often or work with it.

After a short explanation of the VR headset, each subject played the game. In the follow-up questionnaire, the sense of presence, the orientation in VR, and the handling of locomotion is evaluated. The sense of presence was queried with four statements from the standardized igroup presence questionnaire (IPQ) [7]. While the

Item	Code	Statement	Answer Type
Presence	G1	In the computer generated world I had a sense of "being there".	Likert-scale 0 to 6
Presence	SP5	I felt present in the virtual space.	Likert-scale 0 to 6
Presence	INV2	I was not aware of my real environment.	Likert-scale 0 to 6
Presence	REAL2	How much did your experience in the virtual environment seem consistent with your real world experience ?	Likert-scale 0 to 6
Orientation	OT1	I had the feeling to keep orientation during teleportation.	Likert-scale 0 to 6
Orientation	OT2	In which situations did you have the feeling to lose orientation? What led to this?	free answer
Orientation	OT3	I felt like I was keeping the orientation when turning with the joystick.	Likert-scale 0 to 6
Handling	HT1	The handling of the locomotion with the controller was intuitive for me.	Likert-scale 0 to 6
Handling	HT2	In which situations did you experience problems with the handling and why?	free answer

Table 1. Follow-up questionnaire to evaluate teleportation as locomotion technique for the VR game Escapers.

statement G1 is intended to measure the general sense of presence, the other three statements SP5, INV2, REAL2 belong to one of the three items Spatial Presence, Involvement, and Experienced Realism of the questionnaire. All statements can be found in Table 1 and were rated on seven-point Likert scales ranging from 0 to 6, with increasing scores indicating a stronger sense of presence. Orientation during teleportation was assessed with the items OT1 and OT2. Since turns to the left and right were made with the same joystick and are also considered as part of the locomotion, the orientation at turns is measured with item OT3. The statement HT1 is intended to rate the handling of the locomotion. Problems with the handling of teleportation are to be captured by HT2.

4 RESULTS

4.1 Sense of Presence

As shown in Figure 3, all statements of the feeling of presence were rated on the IPQ scale from 0 (weak feeling) to 6 (strong feeling) with 4.30 (SD = 0.82) on average. The statement SP5 was rated the highest with a mean of 5.00 (SD = 1.07). The item Experienced Realism with the statement REAL2 was rated lowest on average (M = 3.13; SD = 0.83). The general statement G1 about feeling present and INV2 associated with the item Involvement were rated with M = 4.73 (SD = 1.03) and M = 4.33 (SD = 1.29).

4.2 Orientation

For the statement OT1 about keeping one's orientation during teleportation, there is a tendency to agree in mean (M = 4.4; SD = 1.55). The statement OT3 about orientation while turning also has a tendency towards agreement (M = 4.1; SD = 1.55). At the statement OT2, three subjects (20%) indicated that they had problems with orientation. The subjects stated that this was caused by the combination of real turns and turns triggered by the controller. Orientation was also affected by the sudden change in position after a teleportation. Especially near doors, walls, and stairs, players often teleport a little too close or a little too far from them. As a result, they lost their overview and have to reorient themselves and correct the distance. Participants suggested limiting the area near walls that can be teleported to. From subjects perspective, players could snap to a predefined position after teleporting to doors so that the distance and angle to a door is less disorienting and more player-friendly. However, the subjects emphasized that in general the feeling of disorientation quickly subsided after a familiarization period. The other 12 participants (80%) had no problems with orientation.

4.3 Handling

The handling of the locomotion with the controller is also rated as rather intuitive by the participants (M = 4.2; SD = 1.29). All mean scores for orientation and handling are shown in Figure 4. Regarding the qualitative feedback on the handling of locomotion, two subjects (13.3%) commented that they had to get comfortable with using teleportation with the controller instead of moving around physically. It was noted that players have to become familiar with the artificial locomotion handling. Three participants (20%) reported

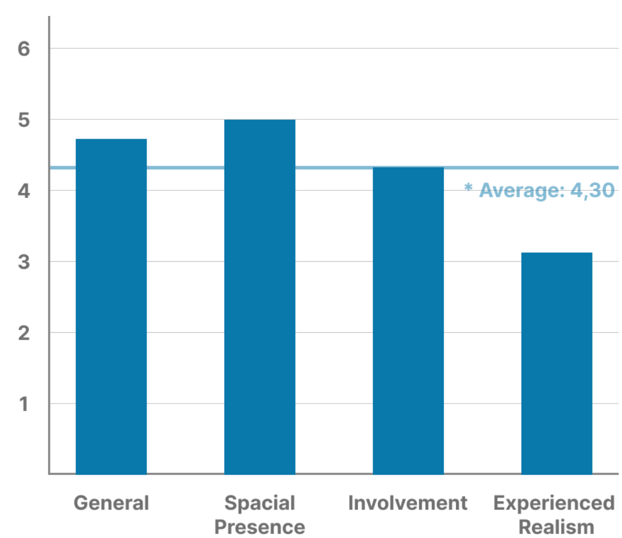

Fig. 3. The evaluation of the statements of the IPQ about the feeling of presence, rated on Likert-scales from 0 to 6.

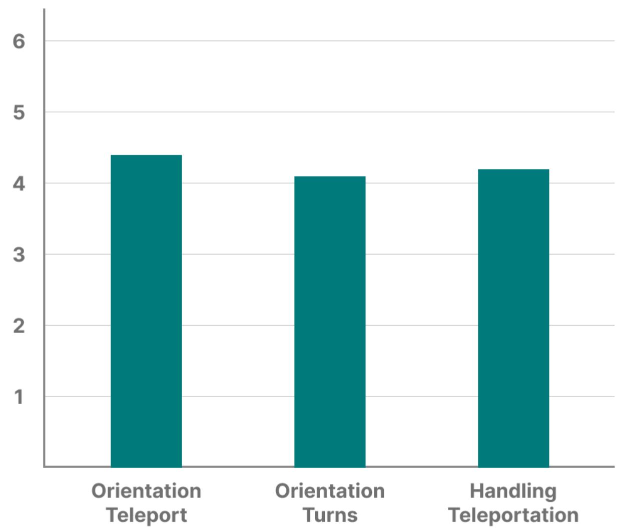

Fig. 4. The evaluation of the statements for orientation and handling with teleportation as locomotion technique, rated on Likert-scales from 0 to 6.

problems with the handling. It was noted that teleportation worked less well, that aiming was difficult, and that rotation and teleportation were sometimes accidentally mixed up. The other 12 subjects (80%) indicated that they had no problems with the handling.

4.4 Hypotheses

Because the subjects rated the handling of the locomotion with teleportation intuitive on average and a majority of 80% stated that they experienced no problems with it, H1 (The handling of locomotion with teleportation is easy and intuitive.) can be confirmed.

Hypothesis H2 (Teleportation will lead to disorientation and a low sense of presence.) can be rejected, because the rating of presence is rather high in mean, measured by the statements G1, SP5, INV2. The evaluation of the statements OT1 and OT3 also tended to the statement that players kept the orientation with teleporation. In addition, OT2 showed that the majority of subjects had no problems with orientation.

5 DISCUSSION

5.1 Sense of Presence

The investigation of the feeling of presence was initiated by the statements of Riecke et al. and Boletsis et al. that teleportation affects this feeling [1, 12]. From the subjects' evaluation, a strong sense of general presence, spatial presence and involvement was found for the game Escapers. When discussing the difference between the results of our study and the results of previous work, it should be noted that previous work explains the break in presence by the visual jumps after teleportations [1, 12]. Nevertheless, these did not lead to low scores in our research. The statement that the jumps caused by teleportation lead to a break in presence cannot be confirmed. Thus, it can be concluded that a high sense of presence can also be achieved with teleportation as locomotion technique. The last statement REAL2 of the presence shows neither a strong nor a weak evaluation. Since REAL2 only captures a realistic representation of the virtual environment, the medium rated result is due to the fact that the focus was not set on a high-fidelity representation in the game.

5.2 Orientation

Oculus cautions in its guidelines for locomotion in VR, that there is a risk of disorientation when using teleportation [11]. The results of the study show that disorientation was experienced by only a very small number of subjects. Moreover, the participants indicated that the feeling of disorientation quickly subsided after a familiarization period with the game. According to the subjects, the reasons for the experienced disorientation were the mix of physical locomotion by own movements and artificial locomotion performed by the controller. Dörner et al. explain that people have learned from reality how physical objects behave and how to interact with them and similar expectations arise for the virtual space [4]. Wang et al. also note that physical locomotion is the most natural way to move around in VR [15]. With this statements, it is assumed that players in VR want to behave as they do in the real world and apply interactions learned from it. If the physical controls are extended by artificial controls (here teleporation), this does no longer fit into the mental model that many players have in VR. Nevertheless, feedback from subjects who lost orientation after teleportations near doors, walls, and stairs should also be considered. For this, improvements should be made in the game, such as limited areas with distance to walls and fixed points at doors to avoid standing too close to them.

5.3 Handling

The results show that teleportation was evaluated intuitive. The majority of participants had no problems with handling. This is supported by previous work in which teleportation was evaluated as simple, fast and with a high usability score [1, 12]. However, not everyone likes teleportation as a locomotion technique, e.g. the aiming and the mixing up with turns is criticized. Mayor et al. believe that there is not one perfect technique in VR, but that different games require individually appropriate techniques [9]. Oculus also recommends including different ways for locomotion if possible, as players' preferences can vary [11].

5.4 Limitations

The study has several limitations that must be considered when interpreting the results. Firstly, the study evaluated only teleportation and no other techniques for locomotion. A comparison could provide information on whether teleportation performs better or worse than other techniques. Secondly, it should be taken into account, that the way the controls are implemented could influence the usability and evaluation of the handling. Lastly, the results are also limited by the sample, in which two-thirds already have experience in VR. In inexperienced user groups or in groups with a lot of experience, other effects could arise.

6 CONCLUSION AND FUTURE WORK

The aim of this research was to find a suitable VR locomotion technique for our game Escapers in which the virtual space is more extensive than the physical one. Due to the complex and nested architecture of the escape room in the game, physical locomotion had to be extended with an artificial locomotion technique. Previous work showed that the teleportation technique leads to less motion sickness than controller-based handling [1, 9] and is easy and intuitive to use [12]. However, there was also evidence in some papers that teleportation breaks the sense of presence due to visual jumps [1, 12] and that there is a risk of disorientation [11]. In a user study with n = 15 participants, the sense of presence, orientation retention, and handling of teleportation as a locomotion technique were evaluated. Results show that a strong sense of presence can be achieved despite visual jumps. It was also shown that the majority retained orientation and perceived the handling of teleportation as easy and intuitive. Consequently, teleportation is considered an effective locomotion technique for VR games with a complex and spacious environment.

In future work, it would be interesting to investigate whether familiaraization effects and the evaluation of presence, orientation, and handling behave differently for players familiar with VR and the teleportation technique. In addition, other locomotion techniques should be implemented and compared with teleportation.

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