The “bizarre” object effect in Virtual Reality

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ABSTRACT

Working memory experiments are typically conducted in minimal settings. Virtual Reality (VR) enables a more immersive and ecologically valid approach to such experiments. In a serial recall study, we investigated working memory performance in classical computer and VR setups. We conducted the task with typically and atypically colored animal stimuli to investigate the bizarreness, or typicality effect. We manipulated the stimuli dimension, presenting the animals in two and three dimensions. In each trial, stimuli appeared in set sizes varying from four to eight items, where the percentage of atypical animals also varied. Our results demonstrate overall consistency across the classical and VR environments, showing better performance in smaller stimuli set sizes. Having more typically colored animals in a memory set improved participant performance, while the dimension of presented stimuli played no significant role. This sheds light on the role of frequency of atypical items within a memory set. Furthermore, our results show that VR technology can replicate traditional computer-based cognitive tasks without impacting task performance.

CCS CONCEPTS

• **Human-centered computing** → *Displays and imagers*; **Virtual reality**; **Empirical studies in HCI**.

KEYWORDS

Virtual Reality, Working Memory, Serial Recall

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1 INTRODUCTION

Human memory constantly engages with environmental surroundings. In the quest to understand memory, experimental research reduces the complexity of these surroundings in controlled laboratory settings which lack ecological validity. Virtual Reality (VR) allows us to investigate perceptual and memory processes in a less artificial and immersive setting, unrestricted by 2D computer screens [21, 25, 54],[26]. VR also allows experimental designs that are not achievable through traditional methods. This may lead to more ergonomic, ecologically valid, and representative results [14]. In our current study, we utilize the capabilities of VR to detail experimental stimuli further to investigate how different stimuli properties, i.e. dimension and color, interact with working memory (WM) performance.

WM is commonly defined as a limited-capacity store that temporarily holds information accessible for various cognitive operations [3, 16, 53]. [6] proposed a WM model that consists of three vital components: i) the phonological loop, which maintains verbal information in a phonological store by inaudibly articulating speech and encoding visual material, such as nameable pictures or written words; ii) the visuospatial sketchpad, which encodes visuospatial information by establishing and manipulating visuospatial imagery; iii) the central executive, which is the control mechanism of these two components [3, 4, 12]. This model of WM however, does not specify how information in WM is linked to long-term memory (LTM; [2]). To address the model's limitations, [4] proposed a fourth component, i.e., the episodic buffer, that is responsible for chunking information and connecting WM, LTM, and the central executive [4, 5]. The episodic buffer facilitates using prior knowledge and experiences to aid current cognitive processing. It is also thought to play a role in the construction of mental representations or "mental models" of events or situations, which are used to guide behavior [5].

Controlled cognitive processes, including those of WM, share limited resources [3, 16, 31, 33, 35, 53], i.e., they compete for the same limited capacity [27, 30, 39]. Research suggests that this also holds for attentional processes that moderate WM [2], which can influence the functioning of the episodic buffer. The ability to chunk information using the episodic buffer allows individuals to manage the limited capacity of WM and store more information in an organized and meaningful way [35]. This can facilitate the processing and manipulation of information in WM, and potentially improve performance on complex cognitive tasks. For example, [17] has demonstrated that attentional load can affect the quality of chunking in WM, with higher attentional load resulting in less effective chunking [17]. Other studies have shown that attentional processes can also influence the selection and integration of information in WM, as well as the transfer of information from WM to LTM (e.g.,[24]).

Color is one of the object features that play a special role in object recognition [11, 41, 49, 50]. [42] observed that objects are recognized more readily when paired with a typical color rather than an atypical one [42]. For example, a tomato, which is an object associated with the color "red" has conceptual information of the color processed differently than a chair, which can have any color. This impact, however, only occurs in the early stages of object processing, while object features are still segregated (before being holistically processed) [11, 50]. Contrasting results can be found in the literature, on the so-called bizarre object effect. Findings showed that the presence of unusual or “bizarre” items within a sequence improved memory performance in free and cued recall [36],[49]. It is still unclear, however, how this effect manifests in serial recall.

We conduct a dual serial recall task, presenting a series of animal pictures and probing participants to report the order and the color of the animals as they appear in the sequence. The serial recall task is a common paradigm used to investigate WM capacity [8, 20]. It investigates the ability to recreate a list of items in the order they were presented. Performance in serial recall tasks is affected by factors such as Set size, item complexity, and distractions [8, 19, 40]. In our task, we manipulated the color of animals, which can appear either in their typical colors or in an atypical color, i.e. “bizarre” color. We also manipulated the dimension of the stimuli (2D and 3D stimuli), the color of the stimuli (typically colored and atypically colored), the set size (4-8 items), and the presentation device (PC and VR). The stimuli were presented in a blocked design, with four variations, namely mostly typical or mostly atypical blocks, as well as 2D and 3D blocks. Stimuli were verified through a recognition survey conducted before the experiment. We then directed participants to perform a dual serial recall task, where they remembered animals, as well as the color they were presented with. Accuracy was assessed to measure performance.

Real-world objects are found to be easier to remember than simple stimuli such as colored squares, oriented lines, or novel shapes [10]. [32] argue that these real-world objects are stored as holistic representations when the memory load is low [32]. Moreover, elaboration of an item leads to stronger combination processes during encoding and thus, improved WM [18, 34]. Presenting items in a 3D virtual environment may allow participants to better encode the spatial relationships of stimuli items, which could facilitate recall performance [29]. Previous research has also found that WM performance is better in VR conditions compared to other tools such as 2D video or text-book when a text and a 3D model of an object are used as learning material [1]. Moreover, [7] found that images are remembered better in VR than in web page visualization [7, 37].

As VR-based experiments provide more complex stimulation and responses, we might expect additional cognitive load [48]. Cognitive load encompasses factors such as task format, stimulus and response complexity, and time pressure, as well as environmental factors, such as noise and lighting, and individual factors, such as age, intelligence, and experience with the task [48]. On the other hand, classical experiments are extremely simplified and do not necessarily minimize cognitive load [22, 28, 47], [52]. Moreover, certain aspects of classical tasks can be quite a burden. Impoverished stimuli may lead to disengagement from the task and mind wandering [46] such that participants struggle to maintain their focus on the task [38]. Thus, we do not seek to derive a measure of cognitive load by simply subtracting the performance of the VR and the classical mediums but rather investigate effects within-task variations of stimuli in both.

We investigate the influence of atypical or “bizarre” colors on serial recall performance. Our second aim is to investigate the usefulness of presenting items in an immersive setting, i.e. in VR compared to a classical setting using a computer screen. We hypothesize that stimuli presented in "bizarre" or atypical colors will exhibit better recall precision compared to objects in their typical colors. In addition, 3D-presented stimuli in VR will exhibit better recall precision compared to 2D ones. As is common for serial recall studies, we vary the Set sizes of stimuli from four to eight, while varying the percentage of typically colored animals in each set. This allows us to infer the influence of these factors on serial recall accuracy.

2 METHOD

2.1 Participants

Thirty-two participants (18 females, ages 20-30, mean age of 26.09 years, SD = 4.75) recruited at a university of technology in Germany, took part in the study. They were divided into two groups (16 to VR and 16 to PC). They all had normal or corrected-to-normal vision and reported no neurological or psychological disorders. The study was approved by the Ethics Committee at the University of Kaiserslautern and participants gave written informed consent before participating. All procedures followed the institution’s ethical standards and the 1964 Helsinki Declaration.

2.2 Stimuli

The stimuli consisted of ten animal pictures and 3D assets, which were paired based on their colors to ensure an equal number of typical and atypical colors as shown in Figure 1. The animals selected for use in the study were: bear, monkey, chick, bee, duck, sheep, rabbit, elephant, cat, and tiger. Each pair represented one of five different colors: brown, yellow, white, gray, and orange. The typical colors were selected based on the typical color variations of each animal, and none of these colors were included in the atypical color list. The atypical colors used in the study were pink, purple, green, blue, and red (see Figure 5). The study utilized six versions of each animal in both 2D and 3D. The HTML color codes were applied consistently to both the 2D images and 3D assets. The 2D items were presented on a billboard in equal sizes. The 3D items were located on the grass at varying distances from the camera to ensure equal sizes. The 3D animals were obtained from the Unity Assets Store.

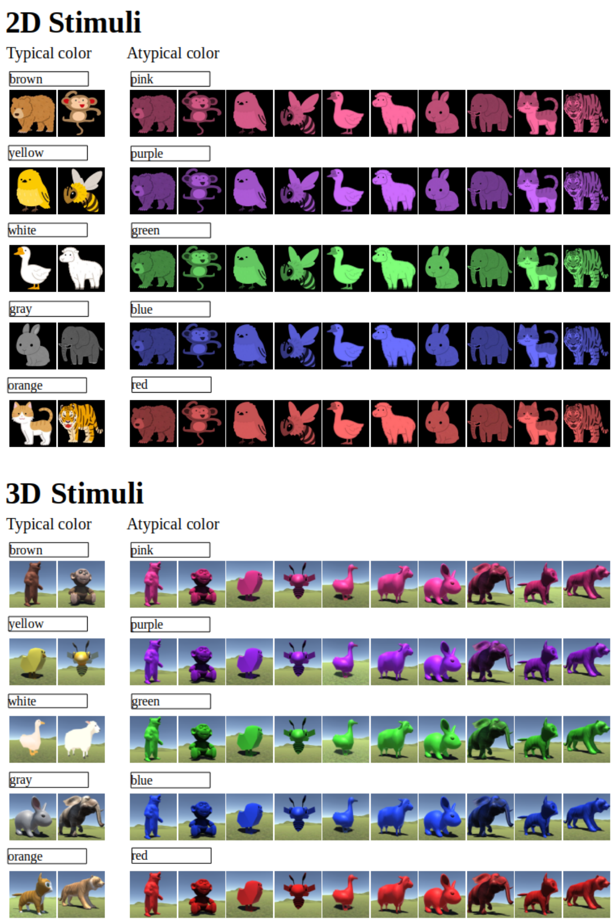

Figure 1: Experimental stimuli

2.3 Apparatus

The study was conducted in a dimly lit room. Tasks were executed on a high-end gaming laptop computer running Windows 10 Enterprise 2016 LTSB 64-bit operating system with an Intel Core i7-8750H processor. The stimuli in the PC version were presented on a monitor (40cm x 30cm) with a screen resolution of 1920 x 1200 and a refresh rate of 90 Hz, running g-sync technology to ensure a stable framerate. Participants were seated 70 cm away from the monitor. For the VR condition, an HTC Vive pro-VR headset with 1080x1200 per eye resolution, and a refresh rate of 90Hz was used. The experiment was programmed using Unity Software, version 2020.1.17f1. For trials in VR, responses were recorded throughout trials using VIVE Pro controllers.

2.4 Design and Procedure

2.4.1 Part one: Picture Rating Survey. Twenty students participated in a picture rating survey. The mean age of the participants was 26.2 years (SD = 4.8). They received course credit for their participation. The survey consisted of 240 questions, with four questions per animal picture. The survey asked to rate the pictures according to Familiarity, Image Agreement, and Visual Complexity. The survey was conducted using a standard PC under the same conditions as the later PC version of the experiment. Participants performed the survey starting with a random category of four (2D mostly typical animals, 2D mostly atypical animals, 3D mostly typical animals, and 3D mostly atypical animals) in a balanced manner to avoid any biases in the results.

2.4.2 Part two: Serial Recall Experiment. Both PC and VR versions included equivalent sequences of events as follows: each trial started with a truck moving from left to right across the participant’s vision. The first randomly chosen stimulus appeared as the truck passed and was presented for 3 seconds. The truck then repeated its movement from left to right, causing the stimuli to disappear as it arrived at their location and then the next one to appear, and so on (see Figure 2). After the final stimulus disappeared, a selection panel with ten animal stimuli was presented to the participant (see Figure 3). The participants then reproduced the sequence of items presented, first by selecting the animal, and then by selecting the color, using either a laser pointer in the VR version or a mouse in the PC version. Accuracy was recorded for both color and animal selection. Participants started the experiment with a random condition out of four conditions (2D mostly typical, 2D mostly atypical, 3D mostly typical, and 3D mostly atypical) in a counter-balanced manner. In the mostly typical blocks, 70%‘ of the items were presented in typical colors and 30%‘ in atypical colors. The opposite was done for the atypical blocks, i.e., 30%‘ of the items were presented in typical colors, while 70%‘ were presented in the atypical ones. Each participant completed two sessions on separate days. Each session consisted of a practice block followed by six blocks of 20 trials each, for a total of 12 blocks with 20 trials each, half using 2D images and half using 3D items. Participants were assigned to either VR or PC conditions and completed the experiment using the appropriate setup. Participants were not required to make any body or head movements throughout the trial to minimize motion sickness effects.

2.5 Analysis

Accuracy was calculated using the proportion of animals and colors remembered in their correct serial position for each trial. Animal selection accuracy was first analyzed in the classical version and compared to the animal selection accuracy in VR. Afterward, color selection accuracy was analyzed in the classical version and compared to the color selection accuracy in VR. A total of 7680 trials

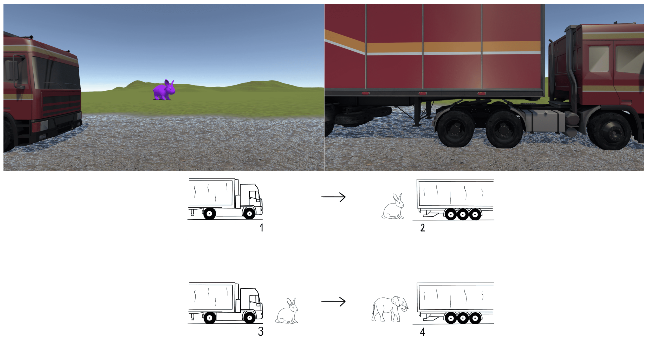

Figure 2: Experimental procedure for one trial

Figure 3: Selection panel

were available for analysis, 3840 for PC and 3840 for VR. We performed two four-way ANOVA, for each dependent variable (animal selection accuracy and color selection accuracy), with the within-subject factors Set size (4-8), Typicality (Typical vs. Atypical), and Animal dimension (2D vs 3D). Presentation device (PC vs VR) was a between-subject factor.

3 RESULTS

3.1 Survey results

Participants were probed to name animals and rate them in terms of familiarity, visual complexity, and image agreement. The analysis of results indicated that familiarity scores differed significantly across colors, F(4, 1187) = 85.807, p < .001, and dimensions, F(1,1187) = 18.257, p < .001. Familiarity scores were significantly higher for typically colored animals in comparison to atypically colored ones (M = 4.46, SD = 0.97). In addition to this, 2D images showed higher familiarity scores than 3D images (M = 3.53, SD = 1.31). Dimension had an interaction with familiarity, F(4,1187) = 4.174, p = 0.004. Post-hoc comparisons showed that typically colored images scored higher than atypically colored images in both 2D (M = 4.51, SD = 0.96) and 3D (M = 4.41, SD = 0.97) conditions. We have analyzed the scores across different animals and colors used in the study. Bear showed the greatest typicality (M = 3.75, SD = 1.36) and image agreement (M = 3.48, SD = 1.31) while monkey showed the lowest typicality (M = 3.24, SD = 1.46) and image agreement (M = 2.94, SD = 1.47). Typicality has been found higher for blue (M = 3.35, SD = 1.27) and green (M = 3.35, SD = 1.28) than pink (M = 2.88, SD = 1.49) and purple (M = 2.79, SD = 1.51).

3.2 Animal Memorization Accuracy

The results for the animal selection accuracy are shown in Figures 4 and 5. The repeated-measures ANOVA revealed no main effect of Device [$F(1, 30) = .272$, $p = .606$]. We obtained a main effect of Typicality [$F(1, 30) = 95.597$, $p < .001$], and for Set size [$F(4, 120) = 217.121$, $p < .001$]. A main effect of Dimension was not found [$F(1, 30) = 1.525$, $p = .227$]. We obtained an interaction effect between Typicality and Set size [$F(4, 120) = 2.984$, $p = .022$]. There were no further significant interactions.

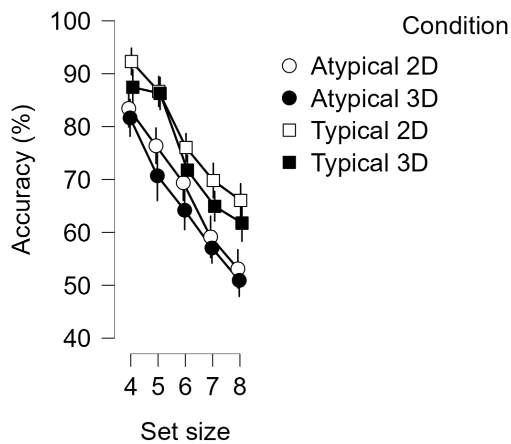

Figure 4: Animal selection accuracy for PC

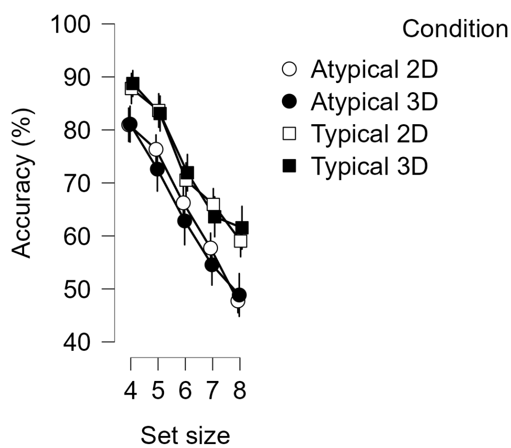

Figure 5: Animal selection accuracy for VR

3.3 Color memorization accuracy

The results for the animal selection accuracy are shown in Figures 6 and 7. The repeated-measures ANOVA revealed no main effect of Device [$F(1, 30) = .285$, $p = .598$]. We obtained a main effect of Typicality [$F(1, 30) = 437.044$, $p < .001$], and for Set size [$F(4, 120) = 270.783$, $p < .001$]. A main effect of Dimension was not found [$F(1, 30) = 0.\text{-}40$, $p = .843$]. We obtained an interaction effect between Typicality and Set size [$F(4, 120) = 26.074$, $p < .001$]. There were no further significant interactions.

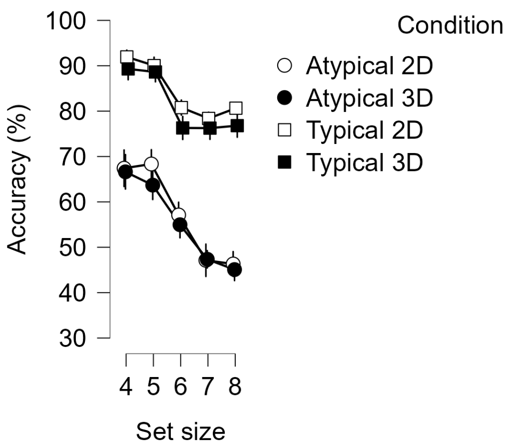

Figure 6: Color selection accuracy for PC

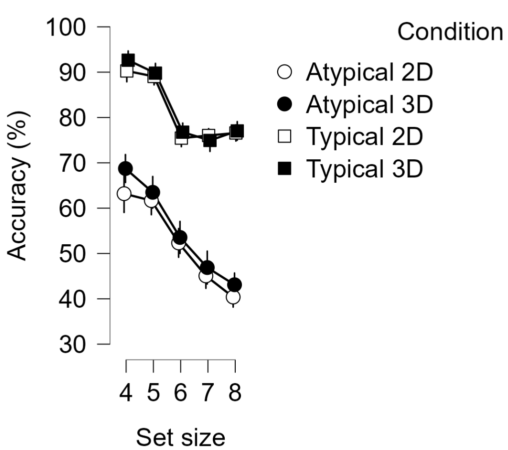

Figure 7: Color selection accuracy for VR

4 DISCUSSION

We explored the effect of the presentation medium and stimuli properties on working memory performance. The task required serial order reconstruction of typically and atypically colored animal stimuli presented in a classical setting and a VR setting. In particular, we examine the “bizarre” object effect and how the frequency of atypically colored animals influences animal recollection. Studying serial recall and the factors influencing it in different contexts allows us to understand the processing and information binding of visual stimuli. Presenting animals in typical colors improved performance for both animal and color recollection, despite color being task irrelevant for the animal recollection task. This can be due to the additional load of performing the dual task of remembering both the animal identity and color for atypically colored animals, whereas for the typically colored animals, they only had to remember the identity. Thus, having too many "bizarre" animals in one trial reduced performance. This shows that frequency has to be considered when investigating the effect of serial recall, controlling for the number of “bizarre” items in the list.

Previous research demonstrated that detailed visualizations lead to better memory performance in 3D images due to additional context. Their work suggested that 3D images are closer to reality than 2D images [10]. Based on this, we predicted that 3D items would be remembered better than 2D items, despite dimension being task-irrelevant. In addition, we expected that presenting items in context using VR would improve memory performance. Our results, however, have not shown any significant differences between 2D and 3D stimuli presentation, as well as no effects of computer and VR-based mediums. We interpret the lack of differences cautiously, as it may be a byproduct of the experimental design, limitations of our experiment, or both. The assets used in this study were limited to open-access materials. Their image quality is limited, yet consistent and considered valid for this investigation. More realistic materials could play a role in better differentiating the presented contexts and dimension manipulation.

In our setup, 3D animals were presented from afar. Depth perception is impaired in faraway 3D objects, which are then perceived more similarly to 2D objects. Additionally, there were differences in the background of the stimuli in 2D and 3D. While both variations stood within a landscape scenario, the 2D animals were placed within a black squared frame. This discrepancy in direct background colors might have introduced confounding factors to the visual processing of the stimuli. Background colors can influence how visual targets are processed over time due to the variation of light wavelength absorption by the retinal photoreceptors [15]. According to one of the participants, the landscape scenario, with green grass and blue sky, facilitated memorization of blue and green-colored animals. Besides, the background square might have introduced the effects of framing. Framing plays a role in visual stimuli location literature, even when the stimulus position relative to the frame has no relevance to the ongoing task. The brain automatically and almost instantly represents a stimulus’s position relative to a background frame [51]. Studies on the influence of background visual features on video game players’ performance, e.g., consider visual traits such as color, and luminosity, motion, and visual complexity, as influencing factors [13]. These factors are the object of study in areas such as cognitive psychology and human factors/ergonomics. Low-level visual features of gaming interfaces can affect top-down attentional processes [13]. Overall, future works should consider providing better visualizations with fewer confounding factors by taking the background set into account.

Additionally, linguistic factors, such as word properties and language use, were not controlled in this experiment. The animals’ or colors’ names in English were not considered in the stimuli selection in terms of the number of letters, frequency of use, and phonological and orthographical neighborhood. Taking that language supports several processes involved in the serial recall, e.g., short-term memory [45], such factors might have played a role in the results reported here [23]. The task instructions were given in English and differences in language background, nativeness, and proficiency were not taken or analyzed in this design. The population were all second-language English speakers with a diverse cultural background, recruited at a university of technology in Germany.

Researchers have found that serial recall performance is affected by long-term knowledge [43]. They show that items that could be transferred into LTM after rehearsal are remembered better in comparison to lesser-known items. Our results are consistent with other studies showing how the WM system can benefit from knowledge in LTM [9], building stronger representations for typically colored stimuli. These results also corroborate previous literature that shows that classical tasks can be transferred well into VR setups [25, 26]. Consistency in the results between VR and computer-based experiments indicates the viability of VR for psychological research. It also indicates that the use of VR does not incur additional cognitive load, which should be taken into consideration when designing experiments for VR. The evolving VR technology may prompt us to move beyond the concept of cognitive load, which subsumes under a single number a broad variety of situational and cognitive variables. Instead, we can focus on direct measures of performance, such as accuracy in experimental tasks.

Finally, this paper is a step toward the integration of stimuli in a scene. While the VR environment is still artificial, it is congruent with reality in the sense that it simulates the natural process of perspective projection[44]. Developmental efforts in increasing the environment and stimuli representativeness to reality, in aesthetics, and multisensory input, are a direction for future studies. [14] suggests that human-centered software designs for VR should be a priority of researchers. When it comes to VR hardware, further developments to overcome motion sickness and visual fatigue are relevant [14]. Such improvements to hardware and software are necessary in search of improving the ecologic and ergonomic validity of VR studies. Research on how stimuli are presented and interact with environmental elements is crucial for identifying factors that impact human cognition and behavior. For example, the parametric variation of the frequency of typicality in future studies can help determine the “sweet spot” of "bizarre" objects’ recall advantage. Taken together similar advances can help describe human cognition in multifaceted scenarios.

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